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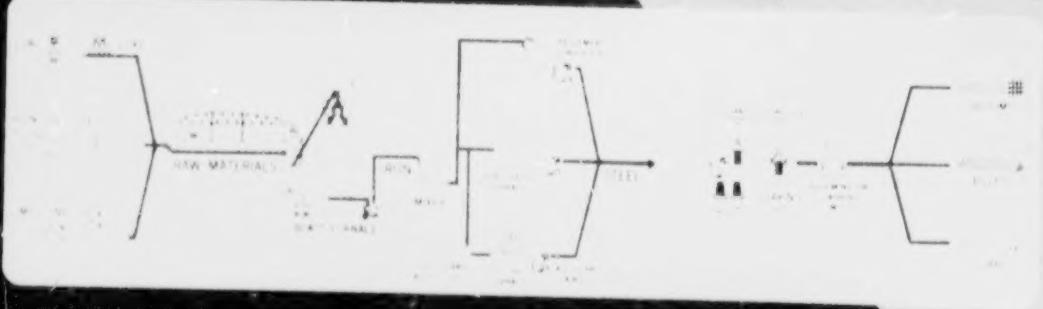
RAW MATERIALS
BLAST FURNACE
IRON
STEEL

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

AIR POLLUTION ASPECTS OF THE IRON AND STEEL INDUSTRY

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Air Pollution

Cincinnati 26, Ohio
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PREFACE

This review of the air pollution aspects of the iron and steel industry was prepared to provide part of the basis for consideration of means for control of air pollution problems that may arise from operation of iron and steel works and activities incident thereto. In this report, published and other information available as of April 1961 has been collected, summarized, and intrepreted. Attention is concentrated on air pollution aspects of the industry, but background information is included to facilitate understanding.

The report is divided into seven major sections. The summary is followed by a description of iron- and steel-making processes and sections on the air pollutants generated and their control, effects of pollutants on the community, public health aspects of emissions, and air pollution laws and regulations. An appendix contains certain information on the size, location, and age of iron and steel works and some historical data.

The section dealing with calculated dispersion of pollutants from open hearth furnaces was prepared by Messrs. P. A. Humphrey and F. Pooler (U. S. Weather Bureau personnel stationed with the Public Health Service). Mr. S. M. Rogers contributed materials concerning legislation applicable to emissions of air pollutants. Dr. May Sherman prepared the discussion concerning effects of emissions on human health, and Dr. C. S. Brandt assisted with matters associated with effects of emissions on vegetation and animals.

The authors express their appreciation to manufacturers of air pollution control devices for their contribution of information and to iron- and steel-making companies for their review of the report.

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ABSTRACT

This report is a summary of published and other information on the air pollution aspects of the iron and steel industry, including coke plants incident thereto. Processes, equipment, and raw materials are briefly described. The magnitude and location of plants and process trends are noted. Air pollutant emissions and means for their control are discussed in detail, with respect to sintering; coke production; blast furnaces; open hearth, Bessemer, electric, and basic oxygen steel-making furnaces; and other operations. The effects of pollutants on community air quality are described, and knowledge of health aspects of pollutants is summarized. Laws regulating pollutant emissions are given, and control equipment and measures needed to comply with certain laws are listed.

Part I

SUMMARY

This report is a summarization of published and other information available as of April, 1961. As in most fields, new information is constantly becoming available, making it necessary for the reader to consider this report in the light of developments since its preparation.

The steel industry is concentrated primarily in about 20 metropolitan areas of the country. Six states, Pennsylvania, Ohio, Indiana, Illinois, Maryland, and New York, contain about three-fourths of the Nation's iron- and steel-producing capacity.

The first major step in the conversion of iron ore into steel takes place in the blast furnace. Iron ore, coke, and limestone are charged in alternate layers at the top and, to promote combustion, a strong draft or blast is supplied by blowing heated air into the lower part of the furnace. To produce 1 ton of pig iron requires, on the average, 1.7 tons of iron ore, 0.9 ton of coke, 0.4 ton of limestone, 0.2 ton of cinder, scale, and scrap, and 4.0 to 4.5 tons of air. In addition to pig iron, the furnace yields about 0.5 ton of slag and about 6 tons of exhaust gases per ton of pig iron produced.

Blast furnaces produce 400 to 2400 tons of pig iron per day. The average furnace produces 1000 tons. At the same time it generates 100 tons of flue dust (200 pounds per ton of finished pig iron). Blast furnace gases contain about 25 percent carbon monoxide. The gases are cleaned to prevent plugging of checkerwork in the heat-recovering stoves, to render the gas usable for heating coke ovens, etc., and to recover process materials such as iron and coke. With only preliminary and primary cleaners 2 to 3 tons of dust would still be emitted each day whereas with high-efficiency control equipment the emission is reduced to less than 0.5 ton per day. Normally, gases are used for heating or are burned in waste gas flares. Carbon monoxide in the gases is oxidized to carbon dioxide, which is of little concern as an air pollutant. The amount of dust produced in ferromanganese blast furnaces is about 50 percent greater than that produced in iron blast furnaces, and the dusts are much more difficult to control. However, electrostatic precipitators have been used with some success in controlling ferromanganese fume.

Two of the most important advances in blast furnace operation in recent years are the use of beneficiated iron ore and the use of sinter in blast furnaces. This has resulted in a major reduction in the number of "slips" in the blast furnace burden and a concomitant reduction in emission of air pollutants associated with slips.

Coke, the chief fuel used in blast furnaces, is the residue after distillation of certain grades of bituminous coal. It is usually produced in byproduct-type ovens although at times a small amount may be produced in beehive-type ovens. As many as 100 byproduct-type ovens may be set together in a battery for ease in charging and discharging the coal and coke. With this process, the volatile matter emitted during coking is piped to special equipment in which its valuable ingredients are extracted. The coke oven gas subsequently is used for heating the coking chambers or in metallurgical processes in the steel plant.

Most of the coal distillation products generated in byproduct coke ovens are confined to processing equipment and are not emitted to the atmosphere. However, smoke and gases escape during oven charging and discharging operations, during carburization, through leaking oven doors, and during coke quenching operations. Fundamental features of a coke oven battery cannot be changed during its lifetime, which amounts to 20 to 30 years. Finally, it is razed and a new structure erected to replace it. Thus, operating procedures and design of new ovens should receive major emphasis for reduction of air pollution.

In beehive-type ovens, distillation products of the coking operation are emitted to the atmosphere. The emissions may amount to 25 percent by weight of the coal charged to the oven and include smoke, dust, sulfur gases, carbon monoxide, and a host of organic compounds.

Sintering plants are used to convert iron ore fines and blast furnace flue dust into a product more suitable for charging into the blast furnace. This is achieved by burning a mixture of ore-bearing fines and coke breeze or other fuel on a slow-moving grate through which combusion air is drawn. Modern sintering plants have capacities of 2000 to 6000 tons of finished sinter per day.

The sintering process generates dust from two sources. The primary source is the combustion waste gas, which entrains dust as it passes through the sinter bed. The average-size machine would discharge about 10 tons of dust daily if uncontrolled (20 pounds per ton of finished sinter), but only about 1 ton daily if centrifugal separators are installed. As the sinter leaves the moving bed, it is broken, screened, and cooled. Dust generated at this point from an average machine totals about 11.2 tons daily (22 pounds per ton of finished sinter).

it may be substantially controlled by use of enclosures exhausted through centrifugal separators. In addition to the dust, about 300 pounds of sulfur dioxide and various amounts of other gaseous combustion products would be emitted daily.

The steel-refining process reduces the quantity of impurities in the pig iron or steel scrap. Common impurities which must be controlled are carbon, manganese, silicon, sulfur, and phosphorous. The most common steel-making furnace is the open hearth, which produces 82 percent of the steel in this country directly, plus another 4 percent that is partially processed by Bessemer converters. Electric furnaces, basic oxygen furnaces, and Bessemer converters are also used. The most important modification in the steel-making processes has been the increasing use of pure oxygen. Today, 20 to 25 percent of the open hearth furnaces use oxygen; oxygen-fuel mixtures are used in electric furnaces to supplement scrap meltdown; oxygen enriched air blasts increase the amount of scrap that may be used in Bessemer converters; and the basic oxygen process (LD process) is gaining wide acceptance in the steel industry.

In the open hearth process for making steel, a mixture of scrap iron and steel and pig iron is melted in a shallow rectangular basin or hearth in which oil, coke oven or natural gas, tar, or producer gas provide heat. Some limestone and other materials are added. Impurities are removed in a slag, which forms in a layer on the molten metal. Oxygen injection into the furnace speeds the refining processes, saves fuel, shortens furnace cycles, and increases steel production rates. A complete cycle (one heat) takes about 12 hours for conventional furnaces, but with the use of oxygen lances or an oxygen enriched fuel the heat time may be reduced to 8 hours.

Open hearth furnaces without oxygen lances generally generate about 5.4 pounds of fume per ton of finished steel or about 1 ton of fume and dust daily. With oxygen lances and continuous operation, the amount of fume produced daily is about 50 percent greater. In terms of the amount of fume per ton of steel produced, the increase is about 25 percent since more steel is produced per day when oxygen is used. Sulfur dioxide and other pollutants formed by the combustion of fuel in the furnace also are emitted. In a very few western plants located where available iron ore has a high fluoride content, emissions of particulate and gaseous fluorides have created damage to vegetation and animals. Because of the small particle size of the fume from an open hearth, only certain types of high-efficiency collectors are effective in removing a large percentage of the fume from open hearth waste gas. Five percent of existing furnaces (44 of 906) are now (March, 1961) fitted with air pollution control devices; they represent 8 percent of the open hearth steel-producing capacity. Planned installations will soon bring the total to 77 controlled furnaces, or 15 percent of the Nation's open hearth capacity. As a result of advances in steel-making technology, the basic oxygen furnace is replacing the open hearth furnace. This will influence future use of open hearth furnaces and installation of air pollution control devices on them.

The basic oxygen process for making steel is carried out in furnaces superficially similar to Bessemer converters. In 1960, about 3 percent of the Nation's steel was produced by this relatively new process. It is also known as the LD (Linz-Donawitz) process. In the basic oxygen furnace, oxygen is blown onto the surface of the bath at high velocity, resulting in violent agitation and intimate mixing of the oxygen with the molten pig iron. An average furnace will produce 100 tons of steel in a heat time of 1 hour. The basic oxygen furnace generates over 40 pounds of fume per ton of steel produced or about 50 tons of fume per day. However, all 12 basic oxygen furnaces in use in the United States as of January 1, 1960, were equipped with high-efficiency controls at the time they were built. Even though these gas-cleaning installations are very expensive, some European operators believe that the value of recovered heat, fume, and dust helps offset the cost.

Electric furnaces used primarily to produce special alloy steels produce 8.5 percent of the Nation's steel. Heat is furnished by direct-arc-type electrodes extending through the roof of the furnace. In recent years oxygen has been used to increase the rate and uniformity of scrap meltdown and to decrease power consumption. An average-size electric furnace will generate 10.6 pounds of fume per ton of finished steel or about 1.3 tons of fume per day. Wide variations are reported. Oxides of nitrogen are formed at a rate of 0.7 to 4.1 pounds per hour per furnace. The quantity formed is a function of the degree of arcing during heating and is not related to furnace size. The characteristically small particle size of the fume limits the type of control equipment capable of giving high-efficiency performance. Fabric filters are most commonly used for emission control, but electrostatic precipitators and venturi scrubbers also are used. Information on the use of air pollution controls is incomplete, but over 10 percent of the 301 electric furnaces at steel plants are estimated to have control equipment.

Bessemer converters may be used to make steel from pig iron; however, they are now essentially obsolete. Their use has declined, and at present, only about 2 percent of the Nation's steel is produced in these devices. The Bessemer converter is a pear-shaped tilting steel vessel lined with refractory bricks and clay. The converter is tilted on its side to receive the charge of molten iron, the air is turned on, the converter is returned to a vertical position, and the impurities are oxidized by air blown through the molten iron for about 15 minutes. An average-size Bessemer converter produces a 25-ton heat of steel in about 30 minutes. The air blast may be enriched with oxygen to increase production 15 to 20 percent. Bessemer converters discharge about 17 pounds of fume per ton of product; an average-size 25-ton-per-heat converter would discharge 10 tons of fume daily. None of the Bessemer converters in use in the United States are equipped with air-cleaning devices. The primary difficulty in adapting control equipment to converters is confinement of the effluent. Although several control methods have been suggested and research is continuing, no reasonable solution to this gas-cleaning problem has been found.

Air pollution measurements have been made in an effort to determine the effect of emission from iron and steel works on community air quality. During and after the 1956 steel strike, studies were made in four iron- and steel-producing communities to determine changes in pollution levels from the strike to post-strike periods. Since certain other activities that cause pollution are also curtailed or shut down during steel strikes, the changes in pollution levels reflect total pollutant emissions from all activities, including iron and steel works. Measurements were made 0.125 to 1 mile away from the steel mills. When the mills were operating, suspended particulate levels were 44 to 171 percent higher, soiling levels were as much as 100 percent higher, and iron content of suspended particulate was 260 to 1080 percent higher than during the strike. A similar study in 1950 showed soiling levels 50 percent greater during the post-strike period. Other studies have shown that pollution levels around steel mills are many times greater than average community levels. Typical levels of pollution in large cities (population 100,000 to 1,000,000) are: dustfall 10 to 60 tons per square mile per month; suspended particulate matter, 100 to 175 micrograms per cubic meter; and soiling index, 1 to 2 Cohs per 1000 linear feet of air. Pollution levels several times these values occur from time to time in some cities. Air samples collected very close to steel mills in heavily industrialized upper Ohio River Valley communities showed dustfall of 123 to 556 tons per square mile per month, suspended particulate matter of 62 to 1238 micrograms per cubic meter, and soiling indexes of 5.3 to 5.5 Cohs per 1000 linear feet. In another study in the same area, however, at air-sampling stations about 1.75 miles from a steel mill, suspended particulate pollution levels were not excessive.

Studies showing high pollution levels near steel mills have been conducted elsewhere in the United States and in England, Germany, Belgium, and Russia.

Iron and steel mill operations may add substantially to the total quantity of particulate matter emitted into the air over a community, unless means to prevent pollutant emissions from the mill are utilized. For example, the weight of particulate matter emitted from 13 open hearth furnaces without air pollution control equipment is roughly equivalent to particulate emissions from about 35,000 coal-fired home heating plants.

No conclusive evidence exists to show whether or not air pollutant emissions from the iron and steel industry, by themselves, are involved in producing adverse effects upon human health. Because of the lack of definitive information concerning the possible hazard of iron- and steel-plant emissions, either by themselves or in combination with other pollutants, studies should be conducted in the laboratory and the field to remedy this deficiency.

Many communities have adopted air pollution control ordinances. Such laws should be tailored to meet the needs of a particular area. Many air pollution control ordinances adopted years ago embody limitations designed to control emission of particlate matter from coal-burning furnaces. Although these ordinances are not the most appropriate for use in bringing about control of emissions from most iron and steel operations, a number of them include such operations among those to be regulated. A few jurisdictions have limited particulate emissions on the basis of the weight of materials introduced into a process (the process weight), exclusive of liquid and gaseous fuels and combustion air. The persent of the process weight that may be discharged decreases as the process weight increases; thus more-efficient dust-collection equipment is required on larger operations than on smaller ones. In addition, the Los Angeles County law (for example) prohibits emission of more than 40 pounds of particulate matter per hour from any process, a severe regulation made necessary by meteorological conditions existing in that area and the large amount of pollutants that were being emitted.

Some ordinances such as that of Allegheny County, Pa., have specific provisions for control of various steel mill operations. The Allegheny County ordinance also prohibits beehive coke ovens and installation of new Bessemer converters until control of their effluent is possible.

Nearly all air pollution control ordinances limit visible emissions, particularly dense smoke. In a few ordinances, this provision has been adapted to include limitations on visible emissions, other than black smoke, that have an opacity equivalent to a plume of black smoke. Since many of the particles emitted from steel mill operations are small and cause a visible plume even when the weight discharged is small, this limitation is very restrictive. A few ordinances limit emission of sulfur dioxide to 0.2 percent of the exhaust gases, and another is based on ground level concentrations of the gas off the plant premises.

To comply with the more stringent regulations for control of particulate matter in Los Angeles and Allegheny Counties and in the San Francisco Bay Area (for examples), most steel mill operations would require highly efficient equipment such as electrostatic precipitators, fabric filters, or venturi scrubbers. Less-efficient collectors would be sufficient to insure compliance with the more-lenient standards of certain other cities such as Lorain, Ohio. The Chicago air pollution law presently (April 1961) exempts certain iron and steel operations from air pollution regulations and provides that research shall be conducted to improve means for control of pollutant emissions. In any case, local ordinances should take into consideration the topographical and meteorological conditions and other factors affecting pollution levels in the area of jurisdiction.

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Part II

THE MAKING OF IRON AND STEEL

Location of Iron and Steel Works

The majority of the iron and steel industry in the United States is concentrated in about 20 metropolitan areas. The larger of these industrial complexes consist of integrated steel operations (blast furnaces and steel-making furnaces, plus accompanying apparatus such as sintering plants, coke ovens, scarfing machines, rolling mills, etc.). The major iron and steel centers are located in or near the following areas,[1] in approximate order of decreasing capacity: Pittsburgh, Pennsylvania; Gary-East Chicago, Indiana; Chicago, Illinois; Youngstown-Warren, Ohio; Baltimore, Maryland; Buffalo, New York; Detroit, Michigan; Weirton, West Virginia-Steubenville, Ohio; Cleveland, Ohio; Birmingham, Alabama; Aliquippa-Midland, Pennsylvania; Bethlehem, Pennsylvania; and Fontana, California. Large iron and steel works are also located in or near Middletown, Ohio; Fairless Hills, Pennsylvania; Lorain, Ohio; Canton-Massillon, Ohio; Johnstown, Pennsylvania; Geneva, Utah; Harrisburg, Pennsylvania; Granite City-Alton, Illinois; and elsewhere.

Listings of the annual capacities of blast furnaces, coke ovens, and steel-making furnaces in the U. S. as of January 1, 1960, are given in Tables A1 through A6 (Appendix).

Locations of Major Iron- and Steel-Producing Centers.

How Iron and Steel Are Made

RAW MATERIALS

Iron ore, plus fuel, flux, air, and water are the basic raw materials required for making iron and steel. Most iron ore minerals are oxides of iron, either hematite (Fe_2O_3) or magnetite (Fe_3O_4), although there may be small proportions of limonite ($2\ Fe_2O_3 \cdot 3\ H_2O$) or siderite ($Fe\ CO_3$) present. In pure form, these minerals contain from 60 to 70 percent iron. In addition to the iron minerals, the ores contain varying amounts of impurities (gangue), which consist mostly of silicon and aluminum compounds, plus moisture.[2, 3, 4] In the United States, depending upon the location and the type of ore, the iron content ranges from about 35 to 65 percent. Lake Superior ores, which supply about 85 percent of the iron ore used in the United States, average about 51 percent iron.[4]

To supply its heat requirements, the steel industry depends upon three major natural fuels: coal, oil, and natural gas. Of these, coal is the most important, since it supplies more than 80 percent of the iron and steel industry's total annual heat and power requirements. The majority of the coal is used in the form of coke for the blast furnace process. Oil and gas are used principally in the manufacture of steel. About 70 percent of the fuel oil used by the steel industry is consumed in metal melting, mostly in open hearth furnaces. Some natural gas is used in open hearth furnaces; however, in recent years, more than 60 percent of the steel industry's consumption was burned in heat-treating and annealing furnaces.[4]

In order to confine the molten metal and also conserve heat, iron- and steel-making furnaces are lined with refractory brick. It is necessary that the refractories have a chemical composition that will not unite undesirable elements with the metal and that will not react with the slag. Three types of refractories are used, acid, basic, and neutral. On this fact rests, in part, the nomenclature of steel-making processes. When acid slag and flux are required to purify certain grades or iron and steel, the refractory brick must contain similar acids to avoid the absorption of foreign elements into the steel. When acid refractories are used in open hearth steel making, the furnace is called an acid open hearth.[4] Silica brick is a popular acid refractory since it has the ability to carry heavy loads at high temperatures. Basic refractories are those that contain magnesia or lime, such as magnesite (magnesium ore) and dolomite (lime magnesium carbonate). Magnesite, the standard material used to make bottoms of basic open hearth and basic electric furnaces, is mined chiefly in California and Washington. The most important of the neutral refractories is chromite (chromium ore), which is used to repair basic open hearths and soaking pits.

The procedures employed in making iron and steel are refining processes; therefore, impurities that ordinarily would not melt at operating temperatures must be removed. Fluxes, such as limestone (calcium carbonate) and dolomite, are used to combine with the gangue elements and carry them off in a fusible slag.

Another additive, namely fluorspar (calcium fluoride), is used in the melting process to make the slag more fluid. As a result of the increased fluidity, impurities are more quickly removed from the molten steel and the rate of heat transfer is increased, also.

Water is used by the steel industry as a cooling agent, as a catalyst, as a conveying medium for transport of materials and for disposal of waste, as a diluent or dispersive medium, as a cleansing agent, and in the production and distribution of heat and power. The industry uses nearly 5 billion gallons (21 million tons) of water daily. A typical blast furnace with a capacity of 1000 tons of pig iron per day will use about 11 million gallons of water in 24 hours, primarily for cooling.[4]

Air is commonly overlooked in a discussion of the materials of steel making. However, without air, combustion could not be supported. Blast furnaces, open hearth furnaces, and Bessemer converters would be useless.[4]

MAKING PIG IRON

The first step in the conversion of iron ore into steel takes place in the blast furnace (Figure 1). The blast furnace itself is a large steel cylindrical structure approximately 100 feet high, lined with heat-resisting bricks. Iron ore, coke, and limestone are charged at the top, and to promote combustion, a strong draft or blast is supplied by blowing heated air into the lower part of the furnace. The air blast is heated in "stoves," which are bricklined regenerators (checker-work) enclosed in a circular steel shell with a flat bottom and dome-shaped top. Modern stoves, usually three per furnace, are 26 to 28 feet in diameter and over 100 feet in height. The checker-work, which consists of a multiplicity of small passageways, contains between 250,000 and 275,000 square feet of heating surface.[3]

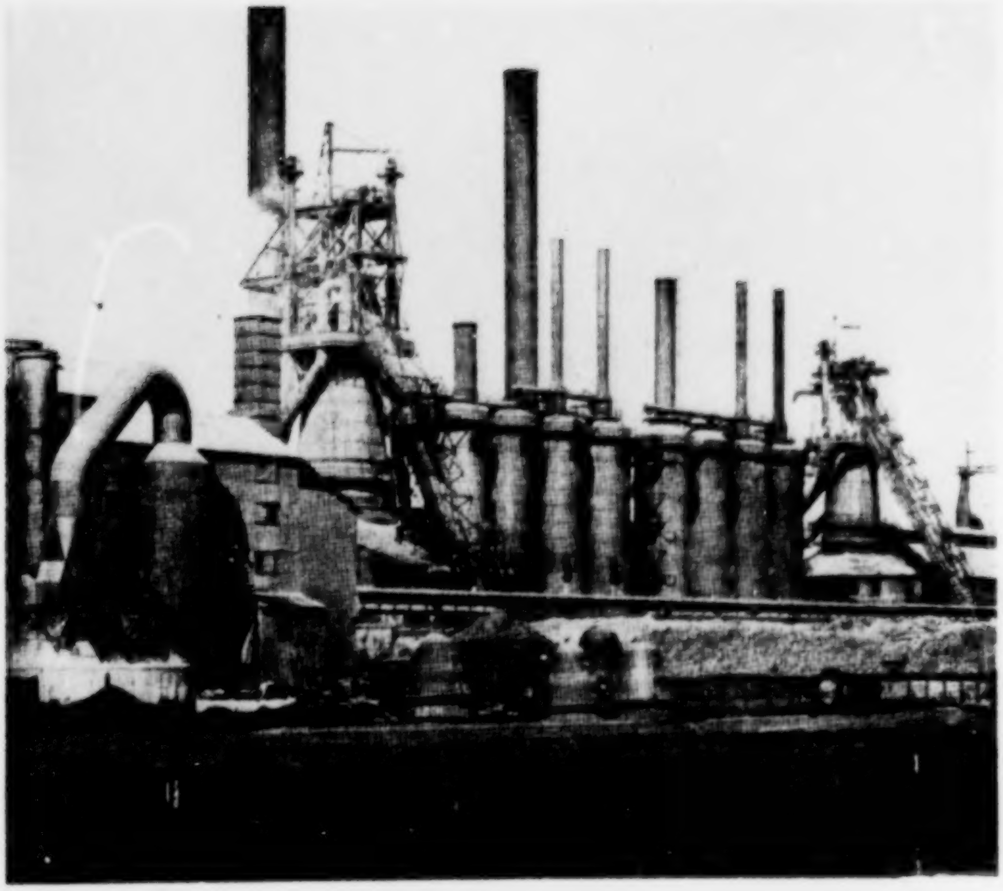

Figure 1. Blast Furnaces and stoves. (Courtesy American Iron and Steel Institute)

One method of "lighting" a furnace is to fill it with more coke and less ore than the regular charge, with much wood at the bottom for quick ignition. Once in blast, the furnace is operated continuously, day and night, for long periods, until the lining wears out or product demand falls off. The furnace is hotter at the bottom than at the top. As the raw materials melt and decrease in volume, the entire mass of the charge descends. The addition of alternate layers of ore, coke, and limestone compensates for the decreased bulk, and thus a constantly descending column of raw materials is maintained within the furnace.[4] As the charge descends through the increasing heat, the iron oxide of the ore reacts with the hot carbon monoxide from the burning coke, and the ore loses a large part of its oxygen. This reaction continues while the charge is in the top half of the furnace. About in the middle of the furnace, the coke acts to take out still more of the oxygen in the ore, and the limestone begins to crumble and react with impurities in the ore and coke to form a molten slag. As the charge enters the zone of fusion, all the materials but the coke become pasty or fused. The iron becomes a porous mass. It then passes through the melting zone and becomes liquid. In this zone the ash from the burned coke is absorbed by the liquid slag, while the iron absorbs silicon from the slag and carbon from the coke.[4]

The iron and slag form a molten mass in the hearth, the slag floating on a pool of iron 4 or 5 feet deep. About every 4 or 5 hours iron and slag are drawn off or "tapped." The slag is tapped more frequently than the iron. From 100 to 300 tons of iron are drawn off at each tap. The hot-metal or ladle cars which receive the iron range in capacity from 40 to 160 tons. The latter usually is a special type of tank car that makes it possible to deliver hotter iron to the steel works, even though it may be 20 miles away. Most of the metal produced in the blast furnace is used in molten form for the manufacture of steel in open hearth and other types of furnaces.[4]

To produce one ton of pig iron requires, on the average, 1.7 tons of iron ore, 0.9 ton of coke, 0.4 ton of limestone, 0.2 ton of cinder, scale, and scrap, and 4.0 to 4.5 tons of air. In addition to the pig iron, the furnace yields about 0.5 ton of slag and about 6 tons of gases per ton of pig iron produced. Air constitutes over one-half of the material entering the furnace, whereas gases constitute more than three-quarters of the materials leaving the furnace. The difference is due to the fact that much of the carbon and oxygen entering as solids, in the coke and ore, respectively, emerges as gases. These gases, piped from the top of the furnace, are rich in carbon monoxide, which can be burned. They are used to heat stoves and generate power. About 20 percent of the gas is required to heat stoves and the remainder is used for steam generation, underfiring of coke ovens, or for the heating of soaking pits. The heating value of blast furnace gas is about 100 Btu per cubic foot, which is about one-tenth the heating value of natural gas.[3]

COKE PRODUCTION

Coke, the chief fuel used in blast furnaces, is the residue after distillation of certain grades of bituminous coal. It is made in two types of ovens, the beehive and the recuperative or byproduct oven. In either type of oven, the distillation or coking process consists mainly of driving off certain volatile matter, leaving in the residue a high percentage of carbon mixed with relatively small amounts of impurities.

The beehive oven is the older, less used of the two types of oven. Their use at iron and steel works has nearly disappeared although a few are still used, especially during times of maximum steel production or when the value of materials recovered in byproduct ovens is particularly low.[23] Its domelike structure is built of refractory or fire-resisting brick. It has a flat floor sloping slightly toward the front. In the roof is an opening through which coal is charged and the products of distillation and combustion escape. A door in the front permits both the regulation of the amount of air admitted during the coking process and the discharge of the coke after the process has been completed. A typical beehive oven is about 12 feet in diameter by 8 feet high, and will hold about 6. 5 tons of coal. It is carefully insulated with loam or clay to prevent loss of heat. As many as 40 of them may be placed in a row.[4]

To start a cold oven, wood and coal fires are stoked until the temperature has reached the intensity needed to start coking. Thereafter, enough heat is retained so that, as one charge is removed through the door at the bottom, a new charge can be put in through the top and the fire maintained. As the heat begins to work, volatile gases are ignited in the coal. The fuel assumes a pasty, or semi-fused, state during the process, and expands appreciably. When the smoke subsides from the hole in the roof of the oven, and the flames shorten at the surface of the charge, coking is finished. The bricks, which have been placed in the door, are torn away, and the coke is sprayed with water. This causes cooling and contraction in the charge, which then breaks into irregular pieces having a column-like structure. This structure distinguishes beehive coke. When cooled, the coke is taken off on a conveyor that ends at a screen. The fuel passes over this "sifter," allowing the dust to fall away, and then slides down a chute into cars for shipment.[4]

In the byproduct coking process, coal is heated in the absence of air. The volatile matter is not allowed to burn away, but is piped to special equipment that extracts its valuable ingredients. After the extraction process, some of the gas (heating value, 550 Btu per cubic foot) returns to the ovens for use in heating the coking chambers and for heating in other processes in the steel plant. These ovens are rectangular in shape. They may be from 30 to 40 feet long, 6 to 14 feet high, and 11 to 22 inches wide. As many as 100 of them may be set together in a battery for ease in charging and discharging the coal and coke (Figure 2). A modern byproduct oven can receive a charge of 16 to 20 tons of coal through ports at the top. The ports are then sealed and coal begins to fuse, starting at the walls of the oven, which may generate heat from 1600° to 2100°F. The fusing works toward the center of the charge from both walls, and meets in the center, causing a crack down the middle of the mass. This crack and the porous structure of the byproduct coke are its distinguishing features. When coking is finished (18- to 20-hour carburizing period), doors at the ends of the oven chamber are opened, and the pusher ram shoves the entire charge of coke into railway cars. The load is taken to a quenching station, where it is watered by an overhead spray. After this, it is taken to a wharf to cool prior to screening.[4]

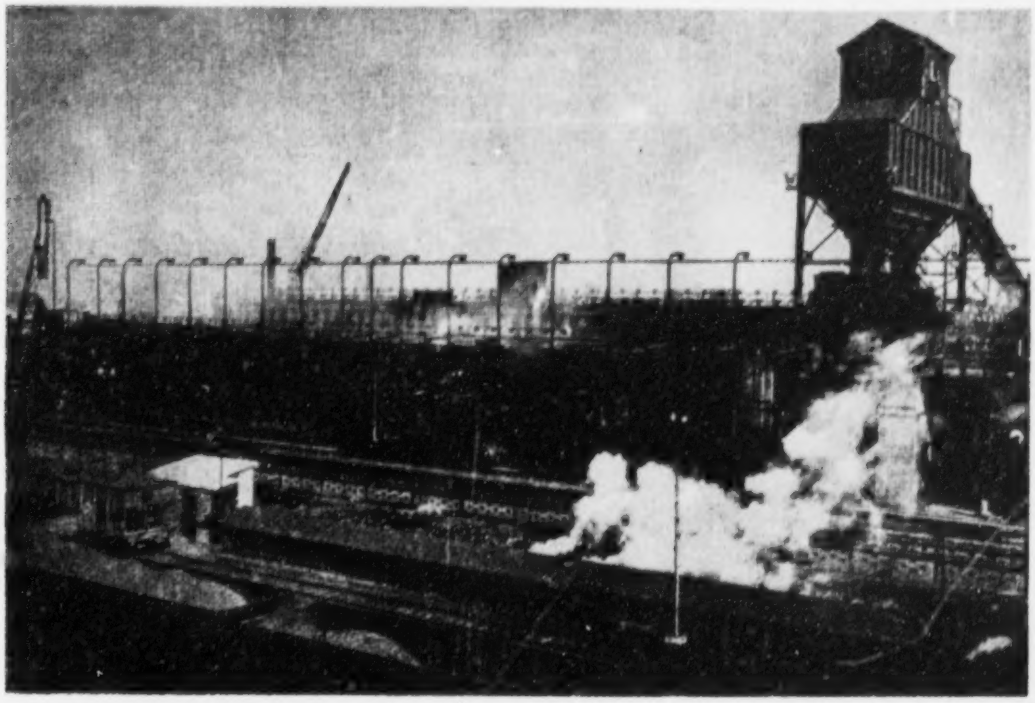

Figure 2. Battery of forty chemical recovery coke ovens. (Courtesy of American Iron and Steel Institute)

The volatile products that have passed out of the ovens are piped to the chemical plant where they are treated to yield gas, tar, ammonia liquor, and light oil. Further refinement of the light oil produces benzol, toluol, and other complex chemical compounds.[4]

The fundamental features of a coke battery cannot be changed during its lifetime, which amounts to 20 or 30 years. At the end of its life it is completely razed and a new structure embodying current technological ideas is erected to replace it.[5]

SINTERING OPERATIONS

Sintering plants are designed to convert iron ore fines and blast furnace flue dust into a product more acceptable for charging into the blast furnace. This is achieved by burning a mixture of ore-bearing fines plus a fuel consisting of coke dust, coal, or wood shavings. Combustion air is drawn through the flat porous bed of the mixture (Figure 3). The principle of sintering is to supply just enough fuel to the material to be sintered so that a sticky mass will be produced, but the material will not be melted sufficiently to cause it to run.[2] The bed is formed on a slow-moving grate (about 6 feet wide) composed of receptacle elements having perforated bottoms, known as pallets. The assembly of such pallets end to end in a hinged or linked arrangement comprises an endless metal belt with large sprockets at either end approximately 100 feet apart.[5] The ignition furnace is either gas or oil fired, and its purpose is to bring the fuel in the charge to its kindling temperature, after which the down draft of air through the bed keeps it burning.

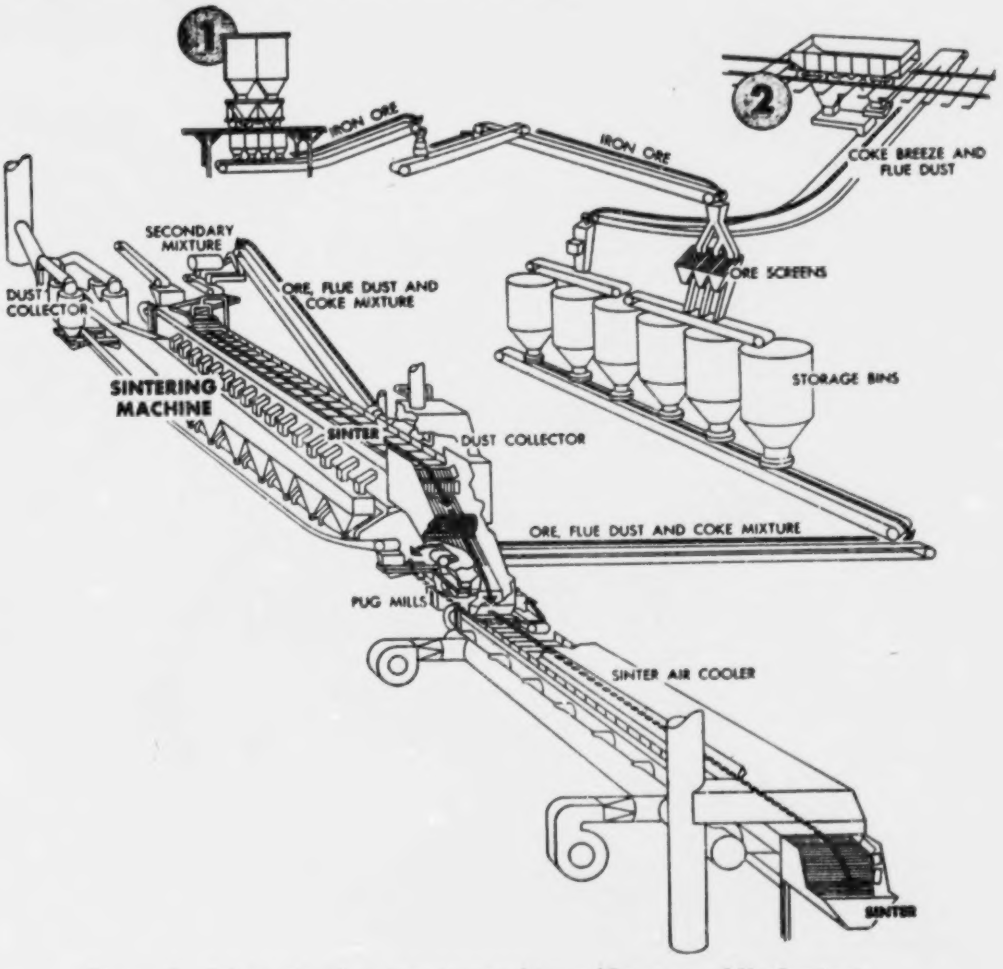
1
2
IRON ORE
IRON ORE
COKE BREEZE AND FLUE DUST
SECONDARY MIXTURE
ORE, FLUE DUST AND COKE MIXTURE
ORE SCREENS
DUST COLLECTOR
STORAGE BINS
SINTERING MACHINE
SINTER
DUST COLLECTOR
ORE, FLUE DUST AND COKE MIXTURE
PUG MILLS
SINTER AIR COOLER
SINTER

Figure 3. Schematic of a sintering machine. (Courtesy of Mechanical Engineering, ASME)

The sintered material is dumped from the grate as it passes over the head sprocket upon a screen, the undersize becoming the return fines, and the oversize, which is still at a red heat in the center, passing to a sinter cooler. The former practice of spraying water on the hot sinter causes a severe thermal shock that tends to crack many of the larger lumps into small pieces. Now, instead, the cooler is usually a large rotating apron upon which the sinter is deposited and cool air is blown through louvers located in the apron. As the cooler reaches a certain position, stationary scraper bars push the sinter off the apron into cars or conveyors.[2]

Modern sintering plants have capacities ranging from 2000 to more than 6000 tons of sinter per day. One plant of the latter capacity has a bed width of 12 feet and a bed length of about 150 feet. Exhaust fans draw air through the bed at a rate of more than 500,000 cfm measured at a temperature of 350°F. This flue gas volume is subject to cleaning for removal of dust or fume.

The exhaust system for control of dust incident to crushing and screening of the finished sinter involves air flows in the vicinity of 150,000 cfm.[5]

MAKING STEEL IN OPEN HEARTH FURNACES

The open hearth furnace is the unit in which some 90 percent of the steel made in the country is produced. In this process, steel is made from a mixture of scrap and pig iron in varying proportions, depending on the cost and availability.[5] The object of the operation is to reduce the impurities present in the scrap and pig iron, which consist of carbon, manganese, silicon, sulfur, and phosphorus, to the limits specified for the different qualities of steel. The refining operation is carried out by means of a slag that forms a continuous layer on the surface of the liquid metal. This slag consists essentially of lime combined with the oxides of silicon, phosphorus, manganese, and iron, which are formed or added during the operation.[6]

Open hearth furnaces are of two types, depending on the character of the refractory material that forms the basin holding the metal. Where the refractory material is silica sand, the furnace is described as "acid," and where the basin is lined with dolomite (or magnesite), it is termed a "basic" furnace.[5] The furnace proper consists of a shallow rectangular basin or hearth enclosed by walls and roof, all constructed of refractory brick, and provided with access doors along one wall adjacent to the operating floor (Figure 4). A tap-hole at the base of the opposite wall above the pit is provided to drain the finished molten steel into ladles. Fuel in the form of oil, coke oven or natural gas, tar from coke making, or producer gas (a gas rich in carbon monoxide manufactured by blowing a limited quantity of air through a hot bed of solid fuel) is burned at one end. The flame from combustion of the fuel travels the length of the furnace above the charge resting on the hearth.[5] Upon leaving the furnace, the hot gases are conducted in a flue downward to a regenerative chamber called checkerwork or checkers. This mass of refractory brick is systematically laid to provide a large number of passageways for the hot gases. The brick mass absorbs heat, cooling the gases to around 1200°F. All the elements of the combustion system burners, checkerwork, and flues are duplicated at each end of the furnace, which permits frequent and systematic reversal of flow of the flame, flue gases, and preheated air for combustion. A system of valves in the flue effects the gas reversal so that the heat stored in checkers is subsequently given up to a reverse-direction stream of air flowing to the burners. In some plants, the gases leaving the checkerwork pass to a waste heat boiler for further extraction of heat which reduces the temperature from around 1200°F to an average of 500° or 600°. Open hearth furnace capacities span a wide range.

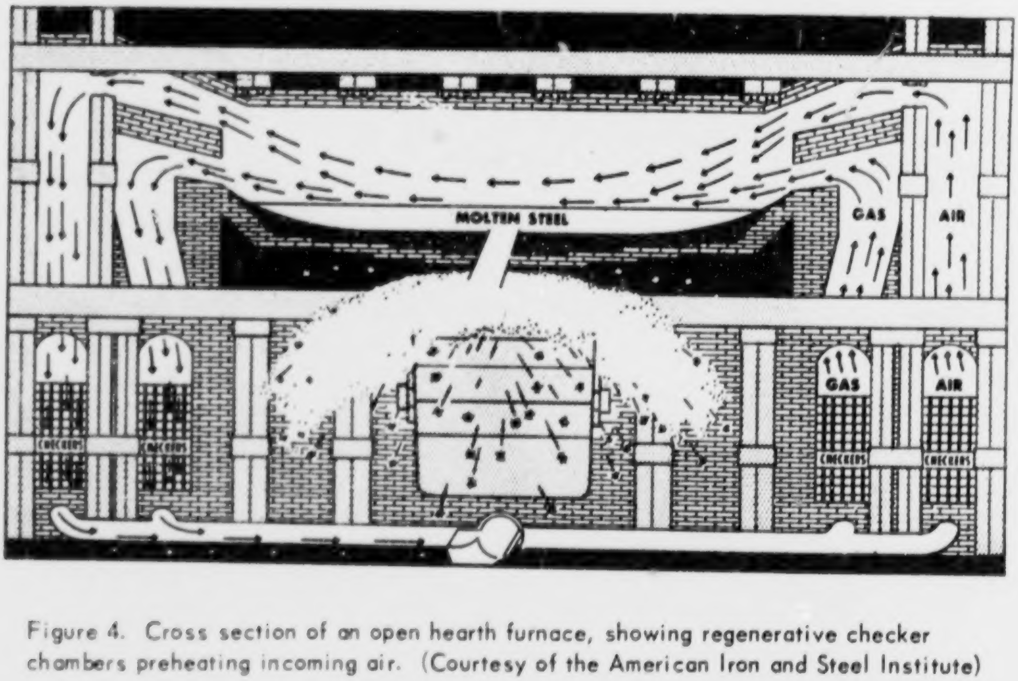

Figure 4. Cross section of an open hearth furnace, showing regenerative checker chambers preheating incoming air. (Courtesy of the American Iron and Steel Institute)

The median is between 100 and 200 tons per heat (batch of finished steel), but there are many of smaller capacity and an increasing number of larger capacity. Time required to produce a heat is commonly between 8 and 12 hours.[5]

The open hearth process consists of several stages: tap to start, charging, meltdown, hot-metal addition, ore and lime boil, working (refining), tapping, and delay. The period between tap and start is spent on normal repairs to the hearth and plugging the tap hole used in the previous heat. During the charging period, the solid raw materials (which usually include a combination of pig iron, iron ore, limestone, scrap iron, and scrap steel) are dumped into the furnace by special charging machines. The melting period begins when the first scrap has been charged. The direction of the flame is reversed every 15 or 20 minutes. When the solid material has melted, a charge of molten pig iron is delivered direct from the blast furnace in large ladles and poured into the open hearth through a spout set temporarily in the furnace door. This is the normal sequence for a "hot-metal" furnace, but in the case of a "cold-metal" furnace, only solid materials (pig iron and/or steel scrap) are added, usually in two "batch" charges.

The hot-metal addition is followed by the ore and lime boil, which is a bubbling action much like the boiling of water and is caused by the oxidized gases rising to the surface of the melt. Carbon monoxide is generated by oxidation of carbon and is characterized by a gentle boiling action called ore boil. When carbon dioxide is released in the calcination of the limestone, the more violent turbulence is called the lime boil.

The aims of the working period are (1) to lower the phosphorus and sulfur content to levels below the maximum level specified, (2) to eliminate carbon as rapidly as possible and still allow time for proper conditioning of slag and attainment of proper process temperature, and (3) to bring the heat to a condition ready for final deoxidation in the furnace or for tapping.[2] At the end of the working period the furnace is tapped, with the temperature of the melt at approximately 3000°F.

The delay period includes waiting time during the heat cycle (e.g. equipment breakdown, tapping equipment in use on another furnace, etc.) plus repair work not usually done during the tap to start period. For normal operation of a 10-furnace shop as a whole, the following breakdown of the heat stages has been made:[7]

Period	Percent of time in indicated period
Tap to start	6
Charging	12
Meltdown	12
Hot-metal addition	3
Ore and lime boil	38
Working (refining)	19
Tapping	2
Delay	8

The use of consumable lances to inject gaseous oxygen into the bath during the refining period and speed the oxidation reactions, shorten heat time, save fuel, and increase production has become more or less standard practice over the last 10 to 12 years. Within the last 3 to 4 years, water-cooled lances inserted through the furnace roof have been coming into prominent use.[8] Frequently, oxygen lances are used throughout the heat with the exception of the charging and hot-metal-addition periods. By use of high oxygen flow rates from hot metal to tap, production rates of 90 to 100 tons per hour are conceivable in a 300-ton furnace. Oxygen consumption under these conditions ranges from 600 to 1000 cubic feet per ton (900 to 1667 scfm during the period oxygen is being added).[9]

One company has been experimenting with oxy-fuel lances, i.e., the use of oxygen in combination with the fuel. This procedure plus the substitution of burned lime for limestone has increased the steel output of a 200-ton furnace from 20 to approximately 30 tons per hour. The oxy-fuel lance was developed for application in the open hearth furnaces of one company and is a relatively new procedure. Oxy-fuel lances currently are being constructed for other companies.[10]

MAKING STEEL IN ELECTRIC-ARC FURNACES

The function of electric furnaces is in general much more specialized than that of open hearth, Bessemer, and basic oxygen furnaces, in that the former are especially adapted to and are primarily used for the production of special alloy steels.[5]

The furnaces employed in electric-arc melting practices in the steel industry are refractory-lined cylindrical vessels with large carbon electrodes passing through the furnace roof (Figure 5). They are normally of the three-electrode, direct-arc type with supply currents ranging from 10,000 to 20,000 amperes. Electric furnaces range in size from about 7 to 22 feet in diameter and produce from 2 to 125 tons of steel per batch. Within the past 4 years, furnaces of 200-ton capacity and with shells approaching 30 feet in diameter have been installed.[5, 11].

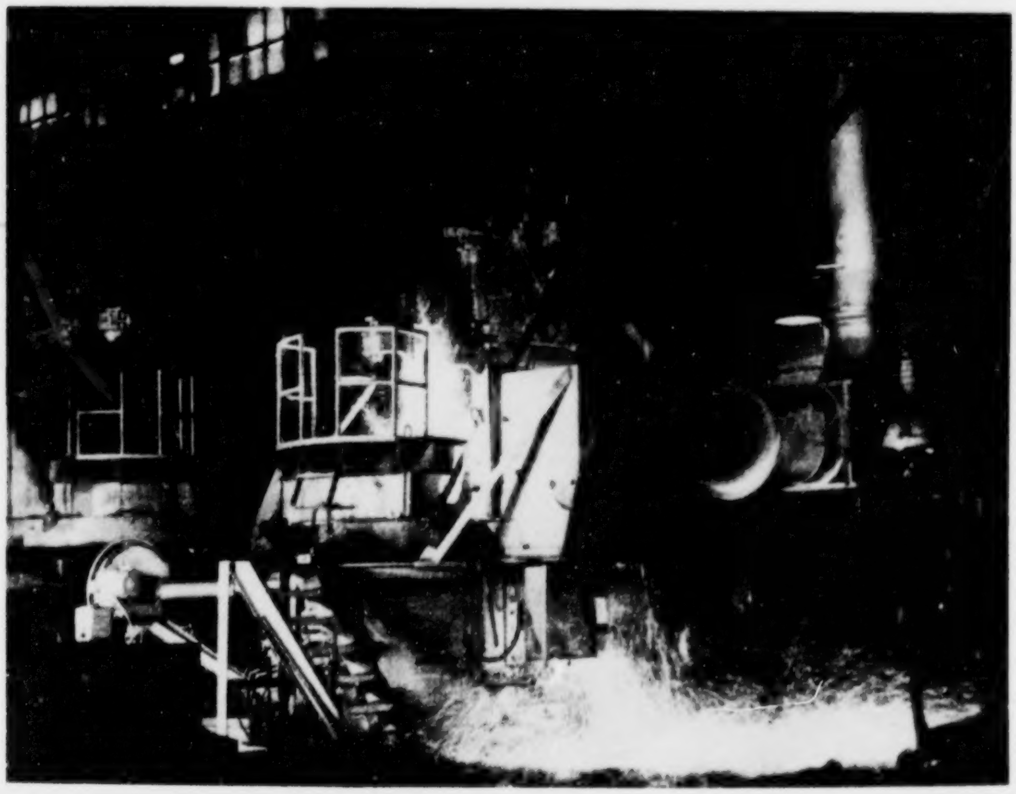

Figure 5. Electric furnace for making steel.
(Courtesy of the Wheelabrator Corporation)

Both acid and basic process cycles are essentially batch operations requiring 1.5 to 4 hours. The cycle consists of the meltdown, the molten-metal period, the boil, the reducing or refining period, and the pour (tap).[11] The stages of this cycle closely approximate those of the "cold-metal" open hearth with the exception that a shorter over-all time is needed.

The impetus in the steel industry, because of the development and expanding use of higher alloy and stainless steel, has lead to the increasing use of the basic lined furnace. This furnace can employ both high- and low-grade alloy scrap and plain carbon scrap to produce steels that meet the stringent chemical, mechanical, and purity specifications for straight carbon, and high- and low-alloy steels.[11]

Electric furnace operations have involved use of oxygen for more than 15 years. The process of utilizing oxygen-fuel gas burners during the scrap meltdown period has been reported to increase production from 15 to 20 percent and decrease power consumption 15 to 20 percent. The use of oxygen has resulted in uniform scrap-melting rates. Evaluation tests on a 50-ton furnace were made at an oxygen flow of 860 cubic feet per ton and a natural gas flow of 545 cubic feet per ton.[13]

MAKING STEEL IN BESSEMER CONVERTERS

Bessemer (Pneumatic) converters serve basically the same function as open hearth and electric furnaces, i.e. they transform pig iron to steel by lowering the carbon, silicon, and manganese content according to the desired quality of the finished steel. They are essentially obsolete and presently account for only 2 percent of the steel produced in the U. S. The Bessemer converter receives a charge of molten pig iron in quantities ranging from 25 to 30 tons in the case of older converters on up to double or more that quantity in more recently constructed units. Converters of 30-ton capacity can effect the complete oxidation reaction in 10 to 15 minutes; however, this production rate advantage over open hearth furnaces is reduced somewhat by the limited extent to which converters can melt scrap metal.[5] Bessemer converters are cylindrical steel vessels lined with refractory and with a spout or nose surmounting the top at an angle with the main axis and are mounted on trunions on which they can rotate (Figure 6). One of the trunions is hollow and serves as an air duct for passage of air from a blower to a chamber, at the bottom of the vessel, known as the wind box. Air passes upward (when the converter is vertical) into the molten metal through holes (tuyers) in the refractory barrier separating the wind box from the molten-metal bath. Air pressure prevents metal from trickling downward through the tuyers into the wind box. When the converter is tilted 90 degrees on its side, the surface of the molten metal is below all tuyers and the air blast can be shut off when the converter is in that position.[5]

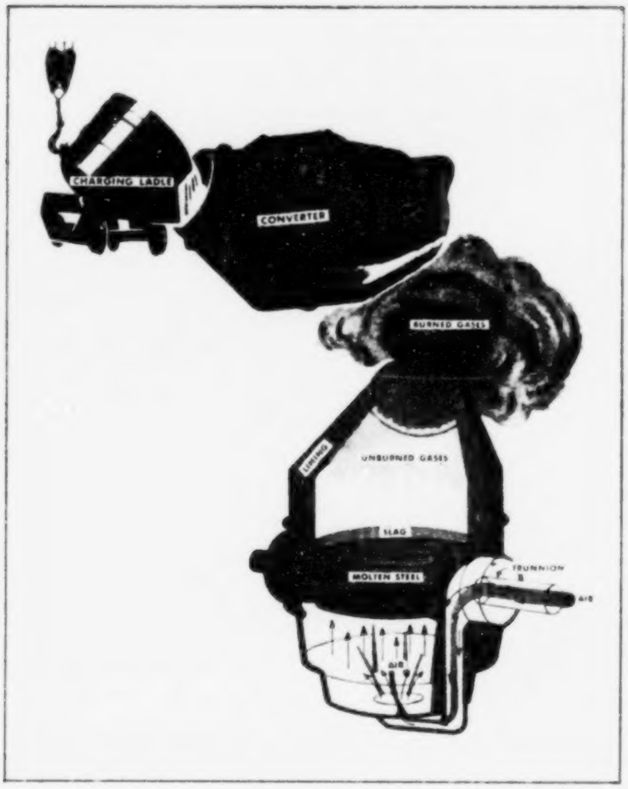

Figure 6. Bessemer converter during charging and blowing operations. (Courtesy of the American Iron and Steel Institute)

The operating sequence of a Bessemer converter is outlined in the following extract:[2]

> The vessel is turned on its trunions until it assumes an almost horizontal position and scrap, scale, or ore is dumped into the vessel, if desired. The molten pig iron is then poured in. The blast is started and the vessel turned to a vertical position and it remains in this position throughout the balance of the blowing period, unless "side-blowing" is resorted to for increasing temperature. The Bessemer blow is usually divided into three parts, the first period, the second period and the after blow. The first period or the silicon blow, begins as the blast is turned on and the vessel turned up. During this period of the blow, a short transparent flame extends from the mouth of the vessel. As the blowing continues the flame starts to lengthen after about four minutes and the second period

> or carbon blow begins. It is during the second period that the flame attains its full brilliance and length, extending as much as 30 feet beyond the mouth of the converter. This flame results from the evolved carbon monoxide burning to carbon dioxide as it comes in contact with the air at the mouth of the converter. The long, brilliant flame which is characteristic of the carbon blow continues until the elimination of carbon approaches completion, whereupon there is a definite change in the appearance of the flame. The length of the flame gradually drops and it seems to fan out. When the blow is subsequently terminated, the vessel is turned down and the blast turned off.

In recent years, it has been reported[14] that the air blast may be enriched with oxygen or a mixture of oxygen and steam may be used instead of air to increase production from 15 to 20 percent.

THE BASIC OXYGEN STEEL-MAKING PROCESS

A smelting process that is superficially similar to the Bessemer converter is the top-blown oxygen converter or the basic oxygen furnace. It is also known by the term Linz-Donawitz (or simply LD) process, derived from the names of two Austrian towns where early developmental work occurred. The converter vessel in this process is similar to a Bessemer converter although considerably larger than most of them.[5] Vessel capacity (since 1954) has gone from 50 to 250 tons and oxygen blown from 3,000 to 20,000 scfm.[15] A principal difference between basic oxygen and Bessemer furnaces is in the means for supplying oxygen to the molten metal. Instead of bubbling air under pressure upward through the bath of molten pig iron, a stream of oxygen is supplied through a water-cooled pipe extending from an overhead position downward into the converter, the end being positioned at some distance above the surface of the bath (Figure 7). The high velocity of the oxygen results in impingement on the liquid-metal surface, which results in violent agitation and intimate mixing of the oxygen with the molten pig iron. Rapid oxidation of the dissolved carbon and silicon (and also of some of the iron) ensues.

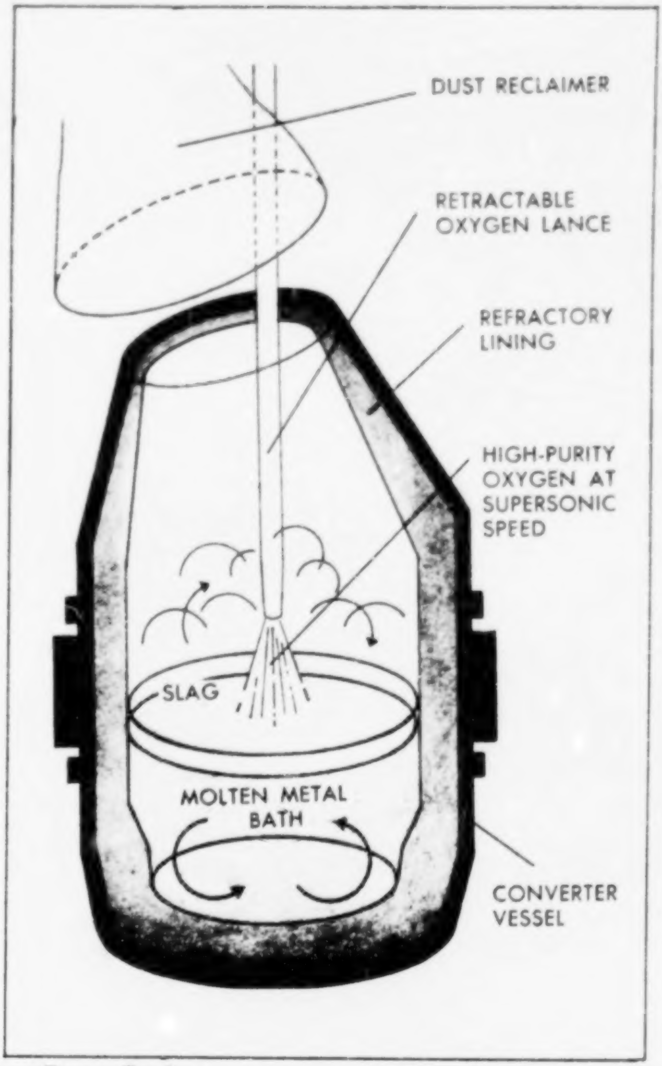
DUST RECLAIMER
RETRACTABLE OXYGEN LANCE
REFRACTORY LINING
HIGH-PURITY OXYGEN AT SUPERSONIC SPEED
SLAG
MOLTEN METAL BATH
CONVERTER VESSEL

Figure 7. Basic-oxygen steel-making furnace.
(Courtesy of the American Iron and Steel Institute)

The following cycle for an 82-ton heat was reported in January 1960:[16]

Sequence	Time, min.
Charge scrap (55,000 lb)	2.39
Charge hot metal (130,000 lb)	2.68
Prepare for oxygen	1.78
Oxygen time (6,500 cfm)	20.22
Temperature and inspection	1.82
Temperature adjustment	5.46
Tapping time	4.32
Slagging off	1.78
Heat time	40.45
Delays	6.12
Tap to tap time	47.02
Production rate 106 tons per hour	

For this same installation, a 108-ton heat has been proposed, with a tap-to-tap time of 55.41 minutes for a production rate of 117 tons per hour.[16]

MISCELLANEOUS OPERATIONS

Heating and Reheating Furnaces

Following the refining operation in the open hearth, Bessemer converter, electric, or basic oxygen furnace, the molten steel is poured from the furnace into a ladle and subsequently into a mold. The solidified steel castings are called ingots. Before these ingots are rolled, the metal is allowed to solidify throughout. A heat supply is carefully manipulated to bring the whole body of metal to a uniform rolling temperature. In the past, ingots were placed in holes in the ground, covered, and allowed to "soak" until rolling temperature was reached. Hence the term "soaking pit" arose. In order to control the soaking operation better and render it adaptable to varying operating conditions, means for supplying heat were introduced. Thus the modern soaking pit is a kind of heating furnace. Throughout the steel plant, heating and reheating furnaces are used to prepare the steel for various finishing processes. Fuels for these furnaces frequently are coke oven gas, blast furnace gas, or other byproducts produced within the steel mill.

Scarfing Machines

As the technology of steel fabrication has developed, so has the requirement for still higher qualities of steel products. Ever increasing attention has been devoted to conditioning of semifinished products. A major element in this area involves the need for removing surface defects of blooms, billets, and slabs prior to shaping, as by rolling, into a product for the market. Such defects as rolled seams, light scabs, checks, etc., generally retain their identity (although not shape) during subsequent forming processes and result in products of inferior quality.

In the earliest days of the development, pneumatic chisels were employed to remove such surface defects. About 25 to 30 years ago the scarfing process developed and today represents an important operation in the making of high-grade steel products. It consists essentially of supplying streams of oxygen as jets to the surface of the steel product under treatment while maintaining high surface temperatures that result in rapid oxidation and localized melting of a thin layer of the metal. Originally the process was a manual one consisting of the continuous motion of an oxyacetylene torch along the length of the piece undergoing treatment. In recent years the so-called hot scarfing machine has come into wide use. This is a production machine adapted to remove a thin layer (one-eighth inch or less) of metal from all four sides of red-hot steel billets, blooms, or slabs as they travel through the machine in a manner analogous to the motion through rolling mills.[5]

Power Plant Boilers

Boilers in steel plants generate steam for driving blowers, electric-power generators, service water pumps, and a multitude of miscellaneous equipment, as well as provide steam for the heating of buildings, shops, and offices and for general process work. The efficient utilization of byproduct fuels provides a surplus, in well-integrated plants, for the generation of electric power. A modern fully integrated plant is capable of generating all of its own power from available surplus byproduct fuel. During the years 1943-1945, 40 to 45 percent of the electrical power requirement of the steel industry was generated by the industry itself.[2]

Magnitude of Operations and Process Trends

RAW MATERIALS AND SINTERING PLANTS

Probably in no other field of the iron and steel industry has so much progress been made as in the improvement of raw materials. In the past, iron ores were charged into blast furnaces as direct-shipping ores from the mines. With beneficiation (removal of impurities such as sulfur and earthy materials), low-grade ores have been made into high-grade concentrates with iron contents ranging from 55 to 68 percent compared with direct-shipping ores of 45 to 53 percent iron content. The production of sinter and pelletized iron ore is now revolutionizing blast furnace practice.[17]

According to Steel Facts, October 1956, there were 103 sintering machines under construction at that time. The new machines (annual capacity 25 million tons per year) were scheduled for completion before the end of 1957 and would bring the total capacity to 63 million net tons per year.[18] In 1959, it was reported that the sintering capacity of United States plants had doubled in the previous 5 years.[19]

In addition to an increased number of sintering plants, the physical dimensions and therefore individual plant capacity have grown in the last few years. The first sintering plants, constructed in 1913, were 3.5 feet wide and 23 feet long. In 1925 a 6-foot-wide machine was developed and in 1959 there were two installations that were 12 feet wide. One was 150 feet long and the other was 200 feet long.[20]

Sinter, which often contains a major part, if not all, of the flux materials for the furnace burden (self-fluxing sinter), together with pellets, has made possible daily iron production increases of more than 50 percent; proportional decreases in coke consumption result in lower iron costs.[17] In a recent test on an 18-foot-diameter blast furnace, production was increased 43 percent and the coke rate (pounds per ton of pig iron) was reduced 26 percent by using a 100 percent self-fluxing sinter burden instead of a burden containing 40 percent completely unfluxed sinter.[21] In the future, as ore bodies of heterogeneous structure are opened up, new beneficiation methods, including magnetic roasting and partial direct reduction, will probably be used.[17]

COKE PLANTS

The number of slot-type (byproduct) coke ovens in use has increased steadily since 1900, except for a slight decline during the depression years (Table A7, Appendix), while the use of beehive ovens has been variable. Coke is used in several industrial processes in the United States. However, slot-type ovens in this report are dealt with only if used in plants connected with the steel industry, while the uses of beehive coke are not specified.

Until the close of World War I beehive coke ovens were the main source of metallurgical coke in the United States, reaching a maximum in 1910 when there were more than 100,000 ovens of this type. However, they have been marginal producers of coke since 1919. In the depression years of the 1930's the number of beehive ovens dropped to 10,816. The demand for blast furnace coke in the years preceding the United States entry into World War II made it necessary to rehabilitate many ovens that had been idle for many years. By the end of 1941, 18,669 ovens were available for producing metallurgical coke. The number remained approximately the same during the war years but dropped to 12,179 at the end of 1945. Increased demand for coke during the Korean War again made it necessary to press into service a substantial number of idle beehive ovens. In 1951 the number of ovens rose to 20,458, with an annual coke capacity of 13.9 million tons. Since that year, however, steel companies have constructed slot-type coke ovens to support expansions in blast furnace facilities, and demand for beehive coke has diminished, resulting in a decline in number and capacity of beehive ovens.[24] At the end of 1959, there were 8500 beehive ovens in existence and the iron and steel industry had 1392 of these.[23]

The capacity of these 1392 ovens was 877,100 tons of coke annually, compared to the total byproduct oven capacity from 13,816 ovens of 71,432,600 tons per year.[1] The primary reason for increased use of byproduct ovens is that this process offers long-range economic advantage from the production of byproduct chemicals.

A byproduct coke oven expansion program was started in the early 1950's and was virtually completed by the end of 1958 (Table A7, Appendix). Most of the new ovens (808) constructed in 1958 were rebuilds or replacements of worn-out ovens; only 117 represented additional capacity. As a result of the construction and modernization program, coke ovens were in the best shape in many years and approximately 72 percent of the active ovens at the end of 1958 were less than 20 years old (Table A8, Appendix). Also, the average age of coke ovens at steel mills dropped from 19 years in 1950 to 13 years in 1958.[22]

With increasing technological advances in the blast furnace process, it is expected that the amount of coke used to produce a given amount of pig iron will continue to decline. The ultimate average is expected to reach 1200 to 1300 pounds of coke per ton of hot metal by 1975. In 1948, 1947 pounds of coke was needed; in 1957, 1703 pounds; and in 1959, an estimated 1500 pounds. The declining coke rate will, however, be offset by a modest growth in steel demand.[25]

With reserves of low-sulfur coking coals limited, the development of new continuous coking and desulfurization methods for the production of coke from marginal coals will take place. Our entire concept of blast furnace coke quality, shape, and sizing will probably change during the next decade.[17]

BLAST FURNACES

In 1960, pig-iron- and steel-ingot capacities were the highest in the history of the industry. In 1940 there were 232 blast furnaces with a total capacity of 55,724,000 net tons per year,[26] whereas in 1960 these values were 263 and 96,520,630 respectively[16] (Table A9, Appendix).

In addition to advances in raw material preparation, there are many recent technological changes in blast furnace practice that tend to increase production. Several new techniques, including elevated blast temperatures with gaseous, liquid, or solid fuel injection, together with moisture (steam) and oxygen additions to the blast, are being used to achieve both decreased coke consumption and increased productivity. Another expected development is the use of higher top pressures with possible power recovery, of the energy of the top gases, by gas turbines.[17] The blast furnace operation is also becoming more automated through the use of automatic stockhouses and charging equipment, as well as use of computers for overall process control. These developments are expected to bring production to or beyond the 3000-ton-per-day performance aim and will lower coke consumption toward the 1250 pounds per ton figure.[17]

Recent developments in the field of direct reduction have been reported.[27] The first commercial operation of a new smelting process that could open a new era for the steel industry is owned by a New York corporation. The process is designed to take low-grade ores, contaminated ores, and extremely fine ores, which would be unsuitable for conventional blast furnace use, and produce a high-quality iron that can be turned into steel more rapidly. The process divides the smelting operation of the conventional blast furnace into two processes. The first, a horizontal, slowly rotating, gas-fired kiln, removes 55 percent of such impurities as oxygen and sulfur from ores of such low grade that blast furnaces cannot handle them and conditions the ore for the second step by a specially designed electric smelting furnace that finishes the job. The slag from the electric furnace can be put through a series of similar furnaces to draw off other metals such as chrome, copper, zinc, and manganese. When developed, this process is expected to be used in remote steel-making areas and not in the large integrated steel operations.

OPEN HEARTH FURNACES

In 1940 steel ingot capacity was 81,619,000 tons[26] per year, and in 1960 it was 148,570,970 [1] (Table A10, Appendix). During the past few years and in years to come, increasing capacity will continue to result through enlargement of existing facilities and improved technology.

The trend of production of steel from open hearth furnaces generally has been upward since 1920 (Table A10, Appendix).

Virtually all open hearth steel comes from the basic rather than the acid process. Although specific data were not obtained, increased capacity in the last few years was probably due to enlargement of existing furnaces and process modifications, plus construction of a few installations in the large size range (300 to 400 tons).

The most important process modification is the increasing use of oxygen, not only during the refining period but also during the meltdown and the ore and lime boils. Oxygen lancing with consumable lances has become more or less standard practice over the last 10 or 12 years. Within the last 2 or 3 years, oxygen injection with roof lances has become prominent. It has been estimated[28] that from 20 to 25 percent of the open hearth furnaces in the United States are equipped with roof lances, and this figure is rapidly increasing.

ELECTRIC FURNACES

The annual steel production from electric furnaces has increased rather slowly since 1920 (Table A10, Appendix). Except in areas of low electric power costs and for special applications (high-quality steel), the electric furnace is not competitive with open hearths.

Electric furnace operators have been using oxygen for more than 15 years. It is used for scrap preparation, scrap cutting in furnace doors, tap hole preparation and clean out, decarbonization, temperature control, and to increase flushing action and improve alloy recovery in stainless steel production.[13]

A recent development has involved the addition of oxygen-fuel gas burners to accelerate scrap meltdown and thereby increase production and reduce power costs. When these burners are included in the design of new furnace installations, their inclusion can conceivably reduce capital expenditures while increasing production capacity.[12]

BESSEMER CONVERTERS

Bessemer converters are obsolete. Their use declined steadily during the first half of the century (Table A10, Appendix), and they presently produce only about 2 percent of the Nation's steel. In 1950 the rated converter capacity in the U. S. was approximately 12,000,000 tons per year, with a considerably greater potential capacity. However, over half of this capacity was represented by blown metal for subsequent use in open hearth furnaces (duplex process).[2] In 1960 there were 21 Bessemer converters with a capacity of 3,396,000 tons of ingots per year plus 11 others that were used in melting the charge for open hearth furnaces.[1]

In most cases the cost of building a Bessemer plant is appreciably less than the cost of an open hearth plant of equivalent capacity. This is offset by the fact that greater blast furnace capacity is required for operation of a Bessemer plant since only a small amount of scrap can be processed (10 percent compared to 35 to 60 percent for open hearth). Oxygen enrichment of the air blast or an oxygen-steam blast may increase the use of scrap in Bessemer converters to about 25 percent.[2]

The Bessemer process has certain economic advantages when scrap is scarce and costly, but there are periods in our economy when scrap is plentiful and cheap. Therefore, economic pressure over a period of years is a controlling factor in the Bessemer steel-making capacity of the Nation.[2]

BASIC OXYGEN FURNACES

As of January 1958, there were 26 basic oxygen furnaces in the world, with an ingot capacity of 7,000,000 tons. Eight of these were in North America, with a capacity of 5,000,000 tons. The largest of these was rated at 65 tons. As of January 1960, 2 years later, there were 90 furnaces built or being built with an annual capacity of 28,000,000 tons. Of these, 22 are in North America, with a capacity of 12,000,000 tons (for existing capacity in U.S., see Table A11, Appendix). Aside from three 110-ton vessels proposed in England, the average vessel used throughout the world (outside of North America) is rated at about 45 tons. On the other hand, in North America, the average vessel size is about 75 tons, with the largest one being 200 tons.[15]

It has been estimated that a basic oxygen steel plant, including the oxygen-generating plant, can be built for less than 50 percent of the cost of an open hearth plant that produces the same tonnage. The basic oxygen furnace has somewhat lower operating costs and produces a product of quality equal to that produced in the open hearth.[29] The basic oxygen process has one limitation, similar to the Bessemer process, in that a limited amount of scrap can be charged. Scrap charged, believed limited to 25 percent originally, is now approaching 35 percent in some shops.[16]

Part III

AIR POLLUTANTS GENERATED AND THEIR CONTROL

SINTERING PLANTS

Rate of Pollutant Generation

According to an article published in 1957, there were 103 sintering plants in the United States with a combined annual capacity of 38 million net tons;[30] thus, the average-size facility at that time would have produced 1000 tons of sinter per day. Dust in the sinter combustion gases from such a plant would be about 10 tons per day. One investigator in the United States reports a tremendous variation of dust emission, 2.7 to 50.7 tons per day, from two similar-sized (1000 to 1250 ton per day) sintering machines.[31]

Three separate British investigators reported that 7.5, 9, and 12 pounds of dust are carried in the combustion gas for each ton of sinter produced.[32, 33, 34] O'Mara reports a wide variation in loading, from 5 to 100 pounds per ton.[31] For the U. S. plants a value of about 20 pounds of dust per ton of sinter is likely. For each ton of sinter produced, there is 200,000 standard cubic feet (scf) of waste combustion gas to be cleaned.[33] This effluent has a temperature of about 160° to 390°F. About 120 to 160 scfm of waste gas is evolved per ton of sinter produced per day with a dust loading of 0.5 to 3 grains per scf.[31]

As the sinter leaves the end of the sintering machine, it is broken, screened, and fed to a cooler. At one British plant where this operation is enclosed and vented, dust loadings were 6.2 grains per scf of discharged gas.[34] The air volume exhausted at this point would be 15,000 to 20,000 cfm for a 1,000-ton-per-day sintering plant. At a 2500-ton-per-day plant, a volume of 40,000 cfm was reported, whereas, at a 10,700-ton-per-day plant, a volume of 192,000 cfm was measured.[34, 35] At an assumed discharge of 17,500 cfm containing 6.2 grains of dust per scf, a 1000-ton-per-day plant would emit 11.2 tons of dust daily if emissions were uncontrolled from the product discharge end of the machine.

A few iron and steel works in the western part of the country use an iron ore mined in southern Utah. This ore contains an unusually large amount of fluoride, and when it is passed through the sintering process, much of the fluorine is driven off.[7] No specific data were found on exit gas loadings, but fluorides are discharged from the sinter plant and open hearth furnaces in sufficient quantity to cause a recognized problem in the community surrounding one or two plants (see elsewhere herein).

Nature of Pollutants

Most of the particles discharged from a sintering machine are very large. About 50 percent by weight of the particles are larger than 100 microns.[33] Particle size distribution has been reported by a British investigator as follows:[32]

> 420 microns	3.7 percent
420 - 178 microns	22.6 percent
178 - 76 microns	36.8 percent
< 76 microns	36.9 percent

A sulfur balance on an English plant shows that the sintering process is an excellent desulfurizer of raw materials; 71 percent of the sulfur present in the raw materials is carried up the stack.[34] Mesabi Range iron ore contains 0.01 percent sulfur on a dry basis.[2] This is equivalent to 0.2 pound of sulfur per ton of ore, and 0.142 pound of sulfur per ton of ore is discharged out the stack. Thus a 1000-ton-per-day sintering plant would emit 284 pounds of sulfur dioxide per day, if all sulfur in the stack was in that form.

Gaseous and particulate fluorides are emitted from a few western sintering plants that are processing high-fluoride-content ore.[7] One review article [36] indicates that hydrofluoric acid (HF) and silicon tetrafluoride (SiF_4) are emitted. Emission of other compounds would seem possible.

Control Methods

Since dust generated in the sintering operation can be returned to the process, most plants are now constructed with centrifugal separators installed as an integral part of the plant to clean the combustion gas. These cyclones operate at an efficiency of over 90 percent by weight on the sinter dust, because of large particle size.[35, 37] Effluents from these cleaners contain from 0.2 to 0.6 grain of dust per cubic foot of gas.[31, 34, 38] Dry-type cleaners are best suited for this cleaning because of the sulfur content of the gas stream.[33] Wet scrubbers would be troubled by corrosion. The first electrostatic precipitator was installed in series with a cyclone to clean the sinter combustion gas in about 1952.[39] The precipitator operates at an efficiency of 95 percent, and the final discharge contains only 0.05 grain per scf. Another similar installation cleans the gas to 0.01 grain per scf.[38] One company is planning to construct a baghouse to control emissions from a sintering operation. These fabric filters should be effective in removing particulate matter. If their service life is satisfactory, they may be used more extensively in the future.

To eliminate dust from the discharge end of the sinter machine, the operation may be enclosed and vented. Cyclones have been used to clean this dust-laden air in both the U. S. and England. A British report shows an inlet loading of 6.2 grains per cubic foot, an efficiency of 93 percent, and a final effluent containing 0.43 grain per scf.[34]

Control of both gaseous and particulate fluorides has been accomplished at one or more sintering plants using a combination of methods. Limestone is mixed with ore to be used in the sintering machine. This reduces the amount of fluorides liberated in sintering by about 50 percent. Gas volume is reduced by recycling about 40 percent of the gases back over the sinter bed. Final clean-up of exit gases is done by feeding powdered limestone into the gas stream to react with gaseous fluorides and form particles that contain the fluoride. The particles are then passed through cyclones and finally an electrostatic precipitator. At one plant, this system reduced emission of fluorides by 96 percent.[7]

COKE PRODUCTION

Nature of Pollutants and Rate of Generation

The main pollutants from byproduct coke ovens are smoke, dust, hydrogen sulfide, and phenols. Other contaminants generated by destructive distillation of the coal include pyridine, cresol, carbon monoxide, ammonia, methane, ethane, and ethylene, in addition to a host of other organic compounds found in coal tar. Some escape to the atmosphere mainly during charging and discharging of ovens, and during carburization through leaking oven doors. Dust also arises from quenching of finished coke.[40]

Gaseous and particulate matter released in the coking operation, except that which escapes from ovens to the atmosphere, are conveyed in ducts to a coal chemical processing plant. Treatment given materials in such plants varies widely. At one plant,[41] tar and water vapor are removed by condensation. The coal tar is dehydrated and sold to refiners or used as fuel in the open hearth.

Ammonia and pyridine homologs are removed by absorption in sulfuric acid. The pyridines are sprung from solution and sold as a crude for further refining. The crystals of ammonium sulfate, which form in the acid solution, are removed, dried, and sold to the fertilizer industry. The gas is further cooled, to condense crude naphthalene, which is recovered and sold as such. The various light oil constituents are next removed from the gas by absorption in straw oil. These oils, benzol, toluol, xylol, etc., are stripped from the straw oil, separated, and refined.[41] The coke oven gas remaining after these operations amounts to about 11,000 cubic feet per ton of coal charged in the ovens. The gas has a gross heating value of 525 to 535 Btu per cubic foot. A portion of the total gas is diverted at this point and used to underfire some of the ovens. The remainder of the gas is pressurized to 15 to 20 psig and distributed throughout the steel plant. The portion used in the open hearth furnaces is treated for hydrogen sulfide removal.[41]

Some pollutants, such as those that escape during the charging and quenching operations, are emitted at only one time during each coking period. However, when a number of ovens are operated in a single battery, they are sequentially operated to effect a nearly constant gas flow from the ovens. Pollutants are, therefore, discharged at a fairly constant rate. No objective data were found on emissions from charging or discharging operations, but it is common to see large clouds of smoke escaping to the atmosphere at these times. These clouds no doubt contain the destructive distillation products listed above. Russian investigators working near plants that may be very different from those in the United States report that sufficient phenol escapes to the atmosphere from coke plants to cause public complaints because of its irritating odor.[42]

Emissions from coke quenching have been investigated to a limited extent. One series of tests indicated an average loading of 0.073 grain per cubic foot for three samples, indicating that emissions are minor.[43] Another investigator reports, however, that emissions are substantial and that a corrosion problem was caused by droplets of water falling out of the plume from the quenching tower.[44] A third group is of the opinion that the quantity of emission is small and that since the particles are fairly large they tend to settle very close to the quenching operation and therefore create no neighborhood problem. This group indicates the corrosion problem mentioned above is due to use of contaminated water for quenching.[5]

No specific data on pollution emissions from byproduct processing plants were found. One would expect some losses to the of the oven because of the distance the gas must travel and the partial obstruction caused by piling up of coal as portions of the oven become nearly filled.[5] One arrangement for minimizing this effect, available for incorporation in new plants, provides two gas-collecting mains and a gas ascension pipe with a steam jet aspirator at each end of the oven. Thus the length of gas travel to the point of exit is halved and escape of smoke is lessened.[5] It should be observed that effectiveness of smoke control with this arrangement is also greatly dependent on the charging operators, who must manually open and close the steam valves supplying the jet aspirators.[5]

Another design feature somewhat similar to the double main consists of a gas-pressure-equalizing main on the side opposite the collecting main. The equalizing main serves simply to connect all ovens to each other through this main; it is not connected to the principal gas main flue. The equalizing main provides an avenue of egress for gas generated during the charging (which cannot leave through the ascension pipe into the principal collecting main) to pass into one of the nearby ovens that, because it is in its coking stage, is at a lower pressure and can thus accommodate this gas. This arrangement is somewhat less positive and, therefore, less effective than the double main.[4]

One oven design element that minimizes the escape of smoke from the oven interior during charging is appropriate spacing of the charging holes in relation to oven volume. The objective in this respect is to avoid piling up of coal anywhere in the oven in a manner that creates a barrier to the free passage of gases from any part of the oven toward the gas takeoff flue. This condition is attained by calculated spacing of the charging holes in relation to the volume of the oven.[5]

Another feature that has received attention in recent years aims to provide an enclosure between the hopper of the larry car and the top of the charging opening to prevent the escape of smoke-laden gases from the oven interior during charging. This takes the form of drop sleeves and shear gates. The operator lowers the sleeve to the top of the oven preparatory to charging the coal and closes the gate of each hopper as soon as it has been emptied, the latter to prevent the passage of gases upward through the hopper. Immediately following this operation the operator trips the dropsleeve to raise it and quickly replace the lid. Then the leaks around the charging-hole lid are sealed either by luting or by dry seal.[5]

Since a part of the problem of allowing free passage of gas from one end of the oven to the other, during charging, is related atmosphere: materials in the coke oven gas and some of the by-products produced.

In beehive coke ovens, all of the materials resulting from destructive distillation of coal are emitted to the atmosphere (see composition above). There are large clouds of smoke and objectionable odors associated with this process. No quantitative data were found. However, a material balance would indicate that about 25 percent of the coal charged to the oven is emitted as gaseous and particulate pollutants. This varies widely, depending on fuel composition and carburization temperature.

Control Methods

The Technical Coordinating Committee (TI-6) of the Air Pollution Control Association has published a review of methods for controlling emissions from coking operations.[5] The following material is taken from the committee's report and includes most of that published.

Soon after an oven has been emptied of coke at the end of the coking cycle, it is refilled with a new charge of pulverized coal, which may range in size from 3-inch lumps down to pulverized material, and since the oven interior is at bright-red temperature, volatilization of gases from the coal mass begins at once and escapes to the exterior as visible clouds of yellow-brown smoke.[5]

Considerable progress has been made over the years in reducing the quantity of such smoke partly in arrangements and practices for minimizing its escape from the interior and partly in shortening the time required for charging, since in the latter respect the sooner this is accomplished and the openings closed, the less is the total emission. Some of the positive accomplishment is ascribable to improvements in coke oven design and some to improved operating practices.[5]

A number of newer design features have been under discussion in recent years, on some of which agreement is general and on others differences of opinion prevail within the industry. One important improvement over older practice includes facilities for aspirating gases from the interior of the oven during charging by means of steam jet aspirators in the ascension pipe elbow, whereas in former times it was the practice to seal off the oven interior from the gas-collecting main during charging. This resulted in the emission of enormous quantities of smoke during this period, in comparison to that under current practice.[5] Even though a steam jet aspirator is operated in the gas ascension pipe during charging, some smoke tends to escape from the openings at the opposite end to the volume of coal charged from a given hopper, attention has been given to means for better control; this has resulted in the development of volumetric sleeves on the top of the larry car hoppers. These make it possible to adjust the bulk of coal in each hopper to match the requirements of ovens of different cubical capacity. A volumetric sleeve makes it possible to charge the correct volume of coal and thus minimize the gas-passage difficulties discussed above.[5]

Any arrangements that reduce the time required for transfer of the coal charge from larry car hopper to oven interior reduce the total escape of smoke; several mechanical devices have been advanced toward this end, including hopper vibrating mechanisms in conjunction with smooth stainless steel liners, cylindrical hoppers and bottom turn-table feeders, and a screw feed mechanism.

Control of the bulk density of the coal mass is one of the factors contributing to coal feed rate as well as to certain production aspects. In those operations where the coal is pulverized and blended, it has become increasingly common to control the mositure content and, by addition of small quantities of oil to the coal, to modify the bulk density further. Oil-sprayed coal moves out of the larry car hoppers with much greater facility, thus reducing time required for charging.[5]

During the oven-charging process, a leveling operation ensues that involves operation of a leveling bar, a mechanism that is an element of the coke pusher equipment. The leveling bar is operated through the leveling bar opening on the pusher side near the top of each oven. Operation of the steam jet aspirator in the ascension pipe of the oven being serviced tends to prevent the escape of much smoke from the oven interior, but it is not entirely successful. To prevent the emission of smoke at this point, each oven can be equipped with a smoke seal box surrounding the leveling bar opening. In conjunction with the effect of the steam jet aspirator, the seal box greatly reduces the escape of gas from the opening, and on batteries having a gas-collecting main on the pusher side, practically eliminates all escape of smoky gases.[5]

During the 18- to 20-hour carbonization period, leakage of smoke from the interior of an oven may occur around the doors unless measures are adopted to minimize it. In older designs the joint between the coke oven door and the jamb is sealed by luting, i.e., by hand-troweling a wet mixture of clay and coke breeze into a channel between the door and the jamb. In recent years a number of self-sealing door designs have appeared in which metal-to-metal contact between a machined surface and knife edge, together with mechanical arrangements for exerting pressure, provides the seal and avoids the disadvantages of the older luting method, which is so dependent for its effectiveness on the attitude of the workmen having this responsibility. It is, however, necessary that a superior maintenance program be applied to this equipment since wear and tear inevitably allows the development of leakage.[5] An optimum maintenance program for self-sealing doors, as proposed by coke oven operators of Allegheny County, Pennsylvania, includes changing the knife-edge material to stainless steel, and adoption of a numerical system whereby a complete history of each door is kept and a system of having operators tag doors to inform the maintenance force of the reason a particular door was taken out of service.[5]

As to luted doors, it it advocated that tamping of the luting after completion of charging be practiced to minimize smoke emission from that source.[5]

At the end of the coking cycle the incandescent coke is transferred from the oven into a coke-quenching car by pushing equipment. The quantity of smoke arising from the mass during the period required for transport to the quenching station is dependent on the degree of coking. Incompletely carbonized coke ("green" coke) gives rise to considerable quantities of smoke; and conversely, thoroughly carbonized coke gives rise to very little smoke.[5]

BLAST FURNACES

Rate of Pollutant Generation

The average blast furnace in the United States has a production capacity of about 1000 tons of pig iron per day.[1] In producing this quantity of pig iron, 110,000,000 to 150,000,000 cubic feet of waste gases containing 100 tons of dust are evolved.[3, 45] Thus, the blast furnace produces 0.1 ton of dust for each ton of pig iron produced.

Bishop described a modern blast furnace producing 1400 tons of pig iron daily.[46] Using a direct proportion of 1000/1400 to convert his reported data to a typical (1000 ton) furnace, he reported the daily input to a typical blast furnace would be: 2000 tons ore, 900 tons coke, 400 tons limestone and dolomite, and 3570 tons air; the daily output would be: 1000 tons pig iron, 600 tons slag, 68 tons coarse flue dust, 32 tons fine flue dust, and 5100 tons blast furnace gas. Expressed another way, the untreated gases from a blast furnace contain from 7 to 10 grains of dust per scf of gas (7000 grains equals one pound). It is common practice to clean these gases before discharging them to the atmosphere.

Carbon monoxide is formed in the blast furnace operation at a rate of about 2200 to 3000 pounds per ton of pig iron produced. Gases leaving the furnace contain about 25 percent carbon monoxide. For a 1000-ton-per-day furnace, carbon monoxide would be formed at a rate of about 55 tons per hour.[2] Practically all of this carbon monoxide is burned for heating purposes or in waste gas flares.

Most of the sulfur entering the blast furnace is contained in the coke, although some is contained in the iron ore and limestone. One might expect this sulfur to burn and leave the furnace as gaseous sulfur dioxide, but it does not, to any large degree. Most of the sulfur goes into the slag, but a little ends up in the pig iron.[2]

Other common pollutants resulting from combustion are probably emitted from blast furnaces, including a relatively small amount of nitrogen oxides, but no data on them were found. Gaseous pollutants associated with combustion also arise from burning blast furnace gases for heating purposes or in waste gas flares.

Operations Causing Pollutant Generation

"Slips" are the principal factor in pollution arising from modern blast furnaces having typical air pollution control equipment.[34, 45] This problem is much less severe today than it was a few years ago. A slip is caused by arching of the furnace charge. The arch finally breaks and the burden slips into the void. There is a rush of gas to the top of the furnace, which develops abnormally high pressures, much greater than can be handled through the gas-cleaning equipment. When this occurs, bleeders or safety valves open to release the pressure; the result is a dense black or red cloud of dust discharged to the atmosphere. Slips not only create air pollution, but also reduce efficiency of the blast furnace and may cause damage to the interior of the furnace.

Blast furnace operators are constantly striving to reduce the incidence of slips, thus increasing efficiency and production and reducing air pollutant emissions. Furthermore, with increased understanding of their cause, further steps are being taken to utilize practices and procedures to eliminate slips. The use of sinter, with a reduction in the amount of fines fed to blast furnaces, has resulted in smoother operations. In recent years the practice of regular "checking" has been introduced in some British mills. This involves easing the blast every 15 minutes or so to cause a controlled minor slip. Since these controlled slips are normally not severe enough to open the safety valves, the release of uncleaned gas is virtually eliminated. Another procedure that has been used is the differential pressure blowing technique.[34] The blower volume is automatically controlled according to the difference in pressure between the top and bottom of the furnace. The blast is automatically reduced if the furnace "tightens up," thus preventing the bleeders from opening and allowing excessive dust discharge.

Nature of Pollutants

Particulate matter from blast furnaces reportedly varies in diameter from 0.25 inch to 0.1 micron,[47] but no detailed particle size distribution was available. From a 1400-ton-per-day furnace, Bishop reported 68 percent coarse flue dust and 32 percent fine flue dust, but again, no detailed values were provided on size distribution. The coarse dust referred to was removed by greatly reducing the velocity of the gas and at the same time suddenly changing the direction of the gas stream. This would indicate that most of the particles were greater than 50 microns in size. The dust contains around 30 percent iron, 15 percent carbon, 10 percent silicon dioxide, and small amounts of aluminum oxide, manganese oxide, calcium oxide, and other materials.

The principal gaseous pollutant arising in a blast furnace is carbon monoxide. However, at nearly all plants, blast furnace gas is used for heating, thus the carbon monoxide is burned to carbon dioxide, which is of little concern as an air pollutant. That carbon monoxide not burned for fuel is burned in waste gas flares. No data were found on other gaseous combustion products that are probably formed.

Although a few iron ores contain relatively large quantities of fluorides, no reports were found to indicate that fluorides are present in important amounts in blast furnace exit stacks. One set of tests indicated emission of 0.7 pound per day from two blast furnaces designed to produce 1450 tons of pig iron per day.[48] However, the furnaces were not using an ore noted for its high fluoride content.

Control Methods

Blast furnace gas is cleaned in three stages; the first two, at least, are used almost universally throughout the industry. The majority of furnaces have secondary cleaning facilities as well.

The three stages and the equipment used in each are:

1. Preliminary cleaning - settling chambers or dry-type cyclones.
2. Primary cleaning - gas washers or wet scrubbers.
3. Secondary cleaning - electrostatic precipitators or high-energy washers.

Dust-laden blast furnace gas, with a dust concentration of 7 to 10 grains per scf is first passed through the preliminary cleaner; upon leaving this unit, it contains about 3 to 6 grains per scf.[45, 46] The gas then passes through the wet scrubbers; effluent from this type of cleaner contains on the order of 0.05 to 0.7 grain per scf of gas.[4, 45, 46] If a secondary cleaner, such as an electrostatic precipitator or venturi scrubber, is employed, the exit gas contains only about 0.004 to 0.08 grain per scf.[40, 45, 49]

Aside from the need for air pollution control, one of the main reasons that the industry cleans blast furnace gas is to render it sufficiently clean for heating coke ovens, boilers, stoves, soaking pits, and gas engines. The blast furnace gas has a heating value of about 100 Btu per cubic foot, but must be cleaned before it can be successfully used. As an example, it is known that checkerwork in the stoves is most efficient for heat recovery if the openings can be kept small. However, the size opening that can be used is dictated by gas cleanliness.[46] For a gas containing 0.2 grain per scf, the minimum opening that can be used without troublesome plugging is 4.5 inches square. If the gas contains only 0.02 grain per scf, the minimum opening can be reduced to 2 inches square.

Blast furnace flue dust is returned to the iron-making process. Since the dust contains about 15 percent carbon, it will help support combustion in sintering machines. The dust also contains about 30 percent iron, which can be put back in the process after sintering.

FERROMANGANESE BLAST FURNACES

Rate of Pollutant Generation

The number of furnaces producing ferromanganese is small. However, effluent from a ferromanganese blast furnace (a 75 to 80 percent manganese iron is produced) is reported to be a greater air pollution porblem than that of an iron blast furnace.[40] In fact, this effluent, if uncontrolled, is said to be the most prolific pollution producer of any of the metallurgical processes.[50] Studies by Bishop in 1951 established a fume loading in the waste gas of 4.5 to 8.5 grains per cubic foot, with an average of 7.5.[45] The emissions from two 350-ton ferromanganese furnaces averaged 9 grains per scf in a gas volume of 135,000 scfm.[39] These two furnaces produced about 125 tons of dust per day. Another investigator reported that electrostatic precipitators collected 100 tons of dust per day from ferromanganese furnaces producing 670 tons per day.[50] This is equivalent to nearly 150 tons of dust per 1000 net tons of metal produced compared to 100 tons per 1000 for iron blast furnaces.

Nature of Pollutants

Fume from ferromanganese blast furnaces contains 15 to 25 percent manganese and 8 to 15 percent alkali.[47] The fume is extremely small, with 80 percent ranging in size from 0.1 to 1.0 micron.[45, 51] properties of ferromanganese blast furnace fume reported by Bishop are shown in Table 1. The waste gas has a slightly higher heating value (120 to 135 Btu/ft^3) than iron blast furnace gas, which is around 100 Btu per cubic foot.[46, 50]

Table 1. PROPERTIES OF PARTICULATE MATTER FROM A FERROMANGANESE BLAST FURNACE (Reference 51)

Component	Content, %
Manganese	15 to 25
Iron	0.3 to 0.5
Total alkali (as Na_2O and K_2O)	8 to 15
Silicon dioxide (SiO_2)	9 to 19
Aluminum oxide (Al_2O_3)	3 to 11
Calcium oxide (CaO)	8 to 15
Magnesium oxide (MgO)	4 to 6
Total sulfur (as SO_4)	5 to 7
Carbon	1 to 2

Apparent density, 12 lb/ft^3

Particle size (average), 0.3 micron

Control Methods

Cleaning ferromanganese blast furnace gas is more difficult than cleaning the usual blast furnace gas. This is due primarily to the high percentage of fine fume.[45] In addition, the temperature of the waste gas is higher,[40] and moisture variations are extremely wide, complicating control by electrostatic precipitators. However, in this country electrostatic precipitators have been used with some success to control ferromanganese fumes. The collected particulate matter weighs only 12 pounds per cubic foot, and there is at present no economical way to make use of collected dust.

OPEN HEARTH FURNACES

Rate of Pollutant Generation

Concentration of dust and fume in the effluent gas from open hearth furnaces after it is passed through the checkerwork has been reported by several investigators (Table 2). The most striking feature of the data is the wide variation in results reported. Some investigators have reported emission rates as related to the several stages involved in producing a heat of steel (Table 3). Again a wide range of values is reported for the same stage of operations; especially high rates were reported during oxygen injection. However, the average emission rate from a hot-metal open-hearth furnace appears to be about 0.4 grain per scf for the conventional furnace and 0.6 for the oxygen-lanced furnace. These values were about the average of emission rates shown in Table 2, and they can be substantiated somewhat by using the 10 furnace shop cycles given by Purvance (see "Open Hearths" under "How Iron and Steel are Made") for one furnace and applying emission rates from Table 3 for each cycle. Stack gas loadings, process cycle times, and stack gas volumes may be converted into total daily emissions from the furnaces. Some results of such calculations are shown in Table 4.

By calculation, data in Tables 2 and 3 may also be converted into terms of dust and fume emission per ton of steel produced. British investigators[54] report emissions of 1 percent or 20 pounds of dust and fume per ton of steel. According to rates given in Table 4, a general average of 4500 pounds of dust and fume per day is emitted during production of 500 tons of steel. This is equivalent to 9 pounds of dust and fume per ton of steel produced.

Table 2. FUME EMISSIONS FROM OPEN HEARTH FURNACES HAVING NO AIR POLLUTION CONTROL EQUIPMENT[a]

Furnace type (hot or cold metal)	Furnace size (net), tons	Gas volume, scfm	Dust loading, gr/scf		Reference number
			Range	Average	
Cold	60	14,400	0.1 to 2.0	0.69	52
Cold	100	n.a.	0.01 to 0.08	n.a.	53
Cold	n.a.	n.a.	0.04 to 0.18	n.a.	54
Hot	110	20,000	0.02 to 0.07	0.04	48
Hot	n.a.	n.a.	0.1 to 1.4	0.43	55
Hot O_2 lanced	n.a.	n.a.	0.07 to 0.4	0.25[b]	54
Hot	n.a.	n.a.	0.11 to 1.26	0.5[b]	56
Hot O_2 lanced	205	40,000	0.1 to 1.2	0.6[b]	57
Hot	225	33,000	0.5 to 2.5[c]	0.43[c]	58, 59
Hot	250	18,000 to 60,000	0.1 to 2.0	0.5	7
Hot	250	n.a.	0.11 to 0.34	n.a.	53
Hot	275	33,500 to 61,800	0.10 to 0.31	n.a.	45
Hot O_2 lanced	330	37,700	0.8 to 2.5	n.a.	60, 61

[a] n.a. indicates that data were not available.

[b] Estimated by the reviewers.

[c] Range data are from an earlier reference than the average data; therefore, the average figure is probably more accurate.

Table 3. VARIATION OF FUME GENERATION WITH THE STATE OF THE HEAT IN OPEN HEARTH FURNACES

Reference Number	52[a]	56	45[b]	57	54	54
Furnace size (net), tons	60	--	--	205	--	--
Effluent gas volume, scfm	14,400	--	33,500 - 61,800	about 40,000	--	--
Stage of Heat	Dust loading at 60° F and 29.9 in. Hg, gr/ft^3					
Charging	0.87	0.11	0.27	0.35	0.17	0.24
Melt down	0.51	0.11	0.54	0.35	--	0.23
Hot metal addition	only cold metal	0.33	0.39	0.45	only cold metal	0.25
Ore and lime boil	--	0.43[c]	0.60	0.82[d]	0.18	0.25
Working and refining	0.34	0.66	0.19	0.87[d]	0.18	0.40

[a] Tests conducted by Menardi & Co. and staff of Columbia Steel.

[b] The investigator was DeVries; it is assumed that grain loadings reported 45 were at a gas temperature of 550°F.

[c] Three values were obtained during lime boil; 0.43 is the median.

[d] High-purity oxygen was injected during this stage by roof lances.

Table 4. PARTICULATE EMISSIONS FROM OPEN HEARTH FURNACES HAVING NO AIR POLLUTION CONTROL EQUIPMENT

Rated furnace capacity (net), tons	Furnace type	Emission rate, lb/day	Reference number
60	Cold metal	2,250	52
225	Hot metal	3,850	59
250	Hot metal	8,000 to 18,000	7
250	Hot metal	2,000 to 6,000	62
300	Hot metal	5,450	63

Gaseous emissions from open hearth furnaces include those usually associated with combustion of fuels. Open hearth fuel may be producer, coke oven, or natural gas; residual fuel oil; crude coal tar; or pitch creosote. Characteristics of these fuels and partial data on the composition of stack gases resulting from their use are given in Table 5.[6] These are British data. Values given by Smith[58] for an American plant indicate 8 to 9 percent CO_2, 8 to 9 percent O_2, 2 to 5 ppm SO_2, 100 to 200 ppm SO_3, 7 to 8 percent H_2O, and the approximate balance as N_2. Nitrogen oxide emissions from four 50-ton furnaces is about 2.6 tons per day.[168] A mixture of about 70 percent gas and 30 percent fuel oil was being used for fuel. Stack gas concentration varied from 500 to 800 ppm at stack conditions and averaged 700 ppm.

Sulfur dioxide is one gas formed by burning most fuels except natural gas. According to the British data in Table 5, a 200-ton open hearth furnace using fuel at a rate that is equivalent to 4 million Btu per ton of steel would emit 136 pounds of sulfur dioxide per hour if the fuel oil contained 1.6 percent sulfur. In the U. S., oil with a lower sulfur content is usually used and therefore sulfur dioxide emissions would be less. Use of coal tar and pitch creosote would produce slightly lesser amounts. Use of coke oven gas would produce more than twice as much sulfur

Table 5. OPEN HEARTH FURNACE FUELS (Reference 6)[a]

	Type of fuel					
	Producer gas	Coke oven gas	Fuel oil	Coal tar	Pitch creosote	Natural gas
Calorific value (Gases, Btu/ft^3; others, Btu/lb	160	500	18,890	16,740	16,780	1,100
Specific gravity	--	--	0.95	1.17	1.18	0.65
Sulfur content (Gases, gr/ft^3; other, %)	1.75	6.5 to 7.5	1.6	1.0	0.75	Traces
Flue gas, with 40% excess air:						
CO_2, %	14.2	6.05	9.6	11.2	11.5	7.26
H_2O, %	6.9	16.4	13.4	11.3	8.9	13.45
N_2, %	74.8	72.0	71.5	72.0	73.95	73.75
O_2, %	4.1	5.4	5.4	5.4	5.6	5.54
SO_2, %	0.07	0.15	0.06	0.05	0.04	nil
Specific gravity	1.02	0.95	0.93	1.00	1.00	0.97
Dew point, °F	105	138	130	123	114	130

[a] British data; American fuels are somewhat different.

dioxide as use of fuel oil.[6] Not all of this sulfur dioxide would be emitted. Some is absorbed in the steel and in the slag. One report[169] states that, on the basis of tests, most of the sulfur emitted from open hearths equipped with waste-heat boilers is in the form of sulfur trioxide, with only a small fraction being present as sulfur dioxide. This was not believed to be unusual in view of the oxidizing atmosphere and the presence of a finely divided catalyst, Fe_2O_3, in the regenerative system.

Fluorides may be emitted from open hearth furnaces both as gaseous and particulate matter. In most instances, when the source of the fluoride is fluorspar used as a flux during the final stage of the heat, the amount emitted is small and does not cause specific air pollution problems. Emission data from one study indicate that 39 pounds of fluorides per day were emitted from an open hearth shop consisting of 13 110-ton furnaces.[48] However, the report is based on limited data. British reports indicate that about half of the fluorine added as fluorspar is emitted.[63, 64] The amount of fluorspar added to furnaces varies widely but averages about 6.5 pounds per ton of steel produced. Iron ore mined in southern Utah contains more fluorides than others, and when this ore is used in a furnace, it can cause higher fluoride emissions. Although no emission data were found, it is known that at least one western plant has been troubled by fluoride emissions resulting from the use of fluorspar fluxes and high-fluoride ore. In the neighborhood of the plant, problems due to fluorides were indicated.[7] The fluorides are reported to be emitted as hydrofluoric acid (HF) or silicon tetrafluoride (SiF_4).[63, 64]

Effect of Oxygen Lancing on Fume Generation

As a means of developing a concept of the effect of oxygen roof lances on generation of particulate matter, calculations have been made for a hypothetical furnace. These are presented in the following paragraphs.

The average-size open hearth in the United States has a capacity of about 175 net tons of steel per heat. A heat takes about 11 hours when oxygen is not injected into the furnace. If oxygen is injected with roof lances at a rate of about 600 cfm for about 3 hours after hot metal has been added and the bath has been melted, the total length of the heat may be reduced to about 9 hours. The average furnace discharges gaseous effluents at a rate of about 35,000 cfm with or without lances.

Fume loading in the exit gases averaged over the heat are about 0.4 grain per scf without oxygen injection and around 0.6 with oxygen injection as indicated above.[55, 57] Daily emission of dust and fume from this average 175-ton furnace is about 2900 pounds for the standard furnace and about 4300 pounds for a furnace with oxygen injection, if no air pollution controls are operating. These values vary a great deal depending on furnace practice and many other factors as indicated by Tables 2 and 3.

The amount of dust and fume emitted per ton of steel produced, based on the assumptions above, would be 7.5 pounds per ton of steel without oxygen injection and about 9.3 with oxygen injection. Thus, on the basis of emissions per unit time, oxygen injection would increase emissions by 50 percent, but on the basis of emissions per unit of production, oxygen injection would increase emissions about 25 percent. These values must be considered only rough general estimates in view of the variables involved and the few data available.

Operations and Variables Affecting Rate of Fume Generation

Although several factors are believed to affect the rate of generation of dust and fume from an open hearth furnace, not many of these have been studied thoroughly. Cold-metal furnaces generally produce less particulates than the-hot metal type.[65] However, if the scrap iron contains oil, oxides, dirt, wood, etc., or if a large amount of galvanized scrap iron is used in the charge, particulates from a cold-metal furnace may be very high.[52] Work by the British has shown that use of pitch creosote and coke oven gas produces three times as much particulate matter as use of coke oven gas alone.[65] In those tests, a V-notched probe was used to measure deposition between the waste-heat boilers and the stack. When oxygen was added to combustion air, particulate matter was reduced by a factor of 2.5. Many tests on a 100-ton cold-metal open hearth and a 300-ton hot-metal open hearth furnace showed that the peek rate of fume formation occurs in the cold-metal furnace at the end of charging and in the hot-metal furnace just after the hot-metal addition.

Bishop has noted that the peak rate of particulates leaving a hot-metal furnace occurs during the ore and lime boil and during oxygen lancing.[57] He attributed the added fuming to the increased agitation of the molten bath and vaporization of the iron resulting from higher localized metal temperatures (5000° to 6000°F) in the vicinity of the lance. Oxygen lancing may increase the rate of fume formation, mostly ferric oxide, as much as 3-fold over that formed during normal operation.[54] Kohlmeyer, investigating the effect of blowing air oxygen on iron carbon melts, found that fuming did not start before the surface was at a temperature of 2138°F, i.e., just above the melting point of the melt, and was at a maximum at 2552°F. When the temperature of the melt exceeded 2732°F, fuming ceased.[65] Holden and other investigators have found that only alloys containing carbon produce dense brown fumes. The British Iron and Steel Research Association has also investigated the influence of metalloids and found that molten iron or molten alloys without carbon produced no fuming when held in a stream of oxygen, whereas with molten iron-carbon alloys fumes were evolved.[65] Other investigators have substantiated that the amount of fume evolved increases with the carbon content of the melt and with the oxygen input rate.[66] Further tests suggest that the depth of submersion of the oxygen lance tip may be an important factor affecting fuming rate.

Nature of Particulate Pollutants from Open Hearths

Most (up to 90%) of the particulates from open hearth furnaces are usually iron oxide, predominantly Fe_2O_3.[55] However during the lime boil period, the percent iron oxide may be less.[67] In cold-metal furnaces where large amounts of scrap are used in the charge, zinc oxides may be predominant during part of the heat. The high percentage of zinc oxide would be due to use of a large amount of galvanized scrap in the charge, a rather unusual circumstance. Strauss[60] studying a 200-ton oxygen-lanced open hearth furnace found that iron oxide averaged about 50 percent of the total particulates over most cycles but reached above 60 percent during working and ore boiling and about 80 percent during oxygen lancing.

Composite dust samples taken over an entire heat show that a great number of the particles, about 50 percent, are less than 5 microns in size; however, the size distribution varies considerably during the heat. One investigator found that whereas 46 percent of the particles in a composite sample (over one heat) were less than 5 microns, about 77 percent of the particles collected during the lime boil were less than 5 microns.[57] For particle technology work a mean particle size of 0.5 micron and a particle density of 5.2 grams per cubic centimeter has been used.[53, 68]

A recent analysis[57] of the composition of an oxygen-lanced open hearth furnace fume gave the following percentages: Fe_2O_3, 89.1; FeO, 1.9; SiO_2, 0.9; Al_2O_3, 0.5; CaO, 0.9; MnO, 0.6; alkalies, 1.4; P_2O_5, 0.5; and S, 0.4. The particle size analysis (composite over entire heat) was as follows:

Diameter, micron	Percent less than (by weight)
2	20
5	46
10	68
20	85
40	93

In number, most particles are below 0.1 micron in diameter.[67] Vajda remarked "Experiments . . . indicate that the outlet dust loading must be down to 0.05 grains per cubic foot to give a clean (visually) stack. Above this a bystander cannot tell whether there is a cleaning unit on the stack or not." [69] However, another investigator found that during decarb lancing 0.05 grain per cubic foot does cause a visible plume.[70] This suggests that the particle size produced during oxygen lancing is smaller than during other stages of the heat.

Air Pollution Control Methods

The iron oxide fumes from open hearth furnaces are hard to collect economically because of four factors: the small particle size (down to 0.03μ), the large volume of gas, the high gas temperature, and the low value of the recovered material.

Some 10 years ago Vajda[69] conducted tests of certain devices for control of open hearth dust and found that the devices tested were not highly efficient. The efficiencies reported on selected control equipment are listed:

Unit Tested	Efficiency, %
Trion precipitator (commercial type)	80.7
Impingo (Pebble filter) 6 in. H_2O pressure drop	77.8
Type N Rotoclone (with gravel filter)	65.7
Type N Rotoclone	49.6
Multiclone	43.4
Type D Rotoclone	22.8

The inlet dust loading on these tests was generally in the range of 0.10 to 0.40 grain per cubic foot at 60°F. Today, iron oxide dust and fume may be removed efficiently by use of three types of collectors: electrostatic precipitators, high-efficiency wet scrubbers (venturi and Theissen Disintegrator), and fabric filters. A review of present cleaning devices for open hearth waste gases has been published.[60]

The first electrostatic precipitator installed on an open hearth furnace in this country was in California in 1950 and 1951.[39] The precipitator cleaned effluent from a 58-ton cold-metal furnace. The precipitator efficiencies were reported to be 98.5 percent, and the dust concentration leaving the precipitators averaged 0.016 grain per scf. Other descriptions of the operation of electrostatic precipitators in open hearths are available in the literature.[59, 61]

A venturi scrubber has been installed on a 220-ton oxygen-lanced open hearth furnace. Operated at a pressure drop of 14 inches of water across the venturi throat, it removed 98 percent of the fume.[49] The effluent averaged 0.04 grain per scf. These data indicate better efficiencies at relatively low pressure drops than do more recent data presented by Bishop.[57] He describes a venturi scrubber system installed on a 200-ton oxygen-lanced open hearth. Efficiencies range from 86 to 98 percent with inlet dust loadings of 0.35 to 0.45 grain per scf and pressure drops of 26 to 40 inches of water. During oxygen lancing with grain loadings of 0.82 to 0.87 grain per scf the efficiency varied from 89 to 99 percent with respective pressure drops of 26 to 40 inches of water. Effluent dust loadings were consistently below 0.10 grain per scf, and with the scrubber was operated at high pressure drops, exit-gas loadings were below 0.05 grain per scf. The higher pressure drops needed to get better efficiency increase operating power requirements considerably.

It was suggested by Pring[56] in 1954, after some pilot plant experiments, that fabric bag filters would be commercially feasible on open hearth furnaces. In his experiments the gases were cooled to 220°F and passed through "Orlon" filter bags. The efficiency was virtually 100 percent. The first installation of a large fabric bag filter plant on a 300-ton tilting furnace using oxygen refining has been reported in England.[71] The capital cost of the bag filter unit is lower than that of an electrostatic precipitator, but the space requirements are great, and the maintenance costs, particularly with the replacement of bags, might be higher. An order has been placed for the first full-scale glass fiber bag filter on an open hearth (oxygen-lanced) furnace in the United States.[72] At another eastern plant, a 10-compartment unit will be equipped with sonic generators to remove the dust cake from the filter fabric.

The extent of existing and near future use of air pollution control equipment is summarized in Tables 6 and 7. Only 44 (4.9 percent) of the 906 open hearth furnaces in the United States in March 1961 were using control equipment. These furnaces represented about 7.8 percent of the annual open hearth steel-producing capacity. There are air pollution control installations presently under construction or to be installed shortly for an additional 33 furnaces, which represent about 7.2 percent of the nation's annual open hearth steel-producing capacity and 3.6 percent of the number of furnaces. When these installations are completed, about 15 percent of the steel made in open hearths will be produced in furnaces with air pollution controls. As a result of advances in steel-making technology, the basic oxygen furnace is replacing the open hearth furnace. This will influence future use of open hearth furnaces and installation of air pollution control devices on them.

Table 6. OPEN HEARTH FURNACES WITH AIR POLLUTION CONTROL EQUIPMENT March 1961 (Reference 73)

Company	Plant location	Number of furnaces with controls	Rated capacity (net), tons	Total annual capacity (net), million tons	Oxygen lances in roof	Type of control[a]
Kaiser	Fontana, Calif.	9	230	1.5	b	E. P.
United States	Fairless Hills, Pa.	9	345	2.7	yes	E. P.
United States	Homestead, Pa.	11	300	3.0	yes	E. P.
United States	Braddock, Pa.	1	205	0.16	no	V. S.
United States	Geneva, Utah	10	310	2.3	yes	E. P.
United States	Torrance, Calif.	4	63	0.24	no	E. P.
Total		44	---	9.9	---	---

[a] E. P. - electrostatic precipitation; V. S. - venturi scrubber.

[b] Two furnaces have oxygen lances in furnace roof; four have oxygen-enriched combustion air; three do not use either.

Control of gaseous and particulate fluoride emissions from open hearth furnaces has been achieved. As previously mentioned, potential fluoride emissions are of concern at only a few western plants where ores containing unusually large amounts of fluorides are used. One installation in operation in Utah[7] has been described. Gases from 10 310-ton oxygen lanced open hearth furnaces are collected in a large duct and conveyed to a battery of eight electrostatic precipitators. Average particulate loading is 0. 5 grain per scf for the shop. Pulverized hydrated lime ($Ca(OH)_2$) is mixed with the furnace gases to react with gaseous fluorides and form particulate matter containing the fluoride. The particles are then removed from the gas stream by cyclone collectors and electrostatic precipitators in series.

Aside from preferential use of low-sulfur fuels, which results in lower sulfur dioxide emissions, no reports of measures for control of gaseous emissions (except fluorides) were found in the literature.

Table 7. AIR POLLUTION CONTROL EQUIPMENT FOR OPEN HEARTH FURNACES UNDER CONSTRUCTION OR TO BE INSTALLED March 1961 (Reference 73)

Company	Plant location	Number of furnaces that will be controlled	Rated capacity (net), tons	Total annual capacity (net), million tons	Oxygen Lances in roof	Type of control[a]
Jones & Laughlin	Cleveland, O.	3	210	0. 52	yes	E. P.
Jones & Laughlin	Pittsburgh, Pa.	11	315	2. 5	1-yes 10-no	E. P.
Bethlehem	Sparrows Pt., Md.	7	375	2. 0	yes	E. P.
Bethlehem	Lackawanna, N. Y.	6	275	2. 48	yes	E. P.
		3	380	0. 79[b]	yes	E. P.
Bethlehem	San Francisco, Cal.	1	75	0. 01	no	F. F.
Republic	Cleveland, O.	2	420	0. 52	yes	E. P.
Bethlehem	Sparrows Pt., Md.	1	390	0. 28	yes	F. F.
Total		33	--	9. 10	--	--

[a] E. P. - electrostatic precipitator; F. F. - fabric filter.

[b] Estimated by authors.

Research and Development

The most promising future developments known of today are effective slag-wool filters, beds of granulated refractory material, and better high-temperature filter fabrics. All have been shown to be capable of high efficiencies.

The American Iron and Steel Institute is sponsoring research at Harvard University on new means of controlling potential emissions from steel-producing operations. A 1-inch layer of slag wool was used as a filter medium in studies that showed 90 percent of the iron oxide fume is removed from a gas stream at 1022°F at a filter face velocity of 1.67 fps.[53, 67] However, in pilot plant investigations the over-all efficiency was only 60 percent. In this test the slag wool, in the form of a slurry, was fed to a moving-chain belt conveyor. The hot gases dried the slurry and formed the filter bed. Difficulty arose through poor mechanical sealing of the bed. A modified unit using a circular conveyor had even lower efficiency, averaging about 44 percent. Decreased efficiency was due to edge leakage during rotation. Research now is centered on developing an economical cleaning method to remove the trapped fume particles. Most promising is the use of sonic shock waves to remove the particles from the in-place filter bed.

Straus and Thring have investigated the fume-collecting efficiencies of beds of different depths of high-temperature insulating brick, crushed and graded between 7 mesh and 5/16 inch. A 9-inch filter bed attained efficiencies of up to 95 percent with a pressure drop of less than 3 inches water gage and gas velocity of 1.7 fps. The average filter efficiency was 80 percent with an average gas velocity of 1.2 fps. The pressure drop increased from 2 to 4 inches water gage during four melting cycles over a 48-hour operation period, when the bed was used regeneratively.[60]

Research investigations seeking means to increase the size of open hearth fume and thus make it easier to collect have been reviewed.[60] Vacek and Schertler have worked on magnetic agglomeration of fume from a basic oxygen furnace. Vajda, using sonic agglomeration, improved the performance of a type W Rotoclone. Silverman has reported work with a screw-type agglomerator.

A study of formation and suppression of smoke in top-blowing processes was initiated at Battelle Memorial Institute as part of the American Iron and Steel Institute's program late in 1960.[95] These studies are satisfactorily explaining some of the sharp differences in experimental results of various other investigations into iron-smoke-forming processes. The studies are still in progress, but they already give confidence to the possibility of effectively reducing the fume from top-blowing processes. Because of the more general applicability of the results, the primary emphasis will continue to be placed on the determination of the mechanism of formation of the fumes. This knowledge will be useful to the entire industry in devising methods of suppressing the fumes produced. Along with the direct study of mechanisms, however, information will be developed that may be of direct immediate use to the steel industry.

ELECTRIC-ARC STEEL FURNACES

The characteristics, quantities, and means for control of pollutants from electric-arc steel furnaces were summarized by Brief, Rose, and Stephan in their paper "Properties and Control of Electric-Arc Steel Furnace Fumes."[11] Much of the following is taken from that paper. For convenience of the reader, original references given by those reviewers are given herein.

Rate of Pollutant Generation

Data on particulates in effluents from a number of electric-arc furnaces are presented in Table 8. A mean quantity of 10.6 pounds of fume is generated per ton of metal in electric-arc steel-melting furnaces, the range being from 4.5 to 29.4 pounds per ton. Values as high as 37.8 pounds per ton have been reported.[79] An assumed "typical" furnace of 50-ton capacity producing five heats per day would generate a mean amount of fume of 2650 pounds per day. Tests have also been reported[82] that show that fume concentrations frequently reach 3 grains per cubic foot, with a maximum of 6. The wide variations are attributable to the following factors: type of furnace process, furnace size, formulation of charge, quality of scrap, cleanliness of scrap, sequence of charge additions, melt-down rate, metal-refining procedure, and pouring temperature.

Emissions of nitrogen oxides from electric-arc furnaces range from 0.7 to 4.1 pounds per hour per furnace. Tests made on large (75-ton) and small (2-ton) capacity furnaces indicate that the size of furnace is not a measure of nitrogen-oxide-producing capability. It has been concluded that the amount formed is a function of the degree of arcing during the heating.[83] No data were found on the amount of ozone, sulfur dioxide, and other pollutant gases discharged.

Variables Affecting Pollutant Generation

Any effects of furnace process or furnace size on fume generation are not obvious in the data presented. No significant difference in fume formation in acid and basic furnace processes is apparent. It has been stated[52, 84] that the quantity of fume per ton of metal processed increases with furnace size, but this relationship also is not evident here.

The quality of scrap charged, however, is of extreme importance, since the inclusion of large quantities of lower-boiling nonferrous metallic impurities in the melt inevitably leads to high concentrations of oxides of these metals in the fume.[74, 77] The cleanliness of the scrap likewise is an important factor because most impurities (paint, oil, grease, wood, fabrics, etc.) are volatilized at the high temperatures within the furnaces.[75]

Fume generation may be affected further by the sequence of charge additions to the furnace. Metal oxide fumes from the melt are normally decreased after slag additions, because of the slag blanket formed.[85, 86] Impurities may then be included within the slag rather than vaporized to the furnace atmosphere. Partially offsetting this reduction is the volatilization of the newly added slag components.

The method employed for metal refining also has a pronounced effect on fume generation. An oxygen lance leads to higher fume release[12] because of the breaking of the slag film by effluent bubbles and because of the extremely high temperatures[87] reached during this operation. These temperatures lead to increased volatilization of the melt constituents. A mill-scale boil or a spontaneous non-initiated boil has a similar but less pronounced effect. Another recognized factor affecting quantity of fume is the pouring temperature. High pouring temperatures required for small or thin-walled castings lead to greater fume formation because of the rapid increase of the vapor pressure of the molten components with temperature.

Although quantative effects of all of the above factors are not apparent from data presented in Table 8, the significance of these factors is clearly shown in either the previous literature or the original data analyzed for this paper. Coulter[74, 75] performed several tests (Table 8, Case A) under identical operating conditions except for differences in cleanliness and quality of the scrap charged. The amount of fume per ton of metal melted increased 100 percent when dirty, subquality scrap was used. Substantiation of these effects is reported by Kane and Sloan.[77] Their tests (not given on Table 8) show an increase of over 40 percent in the amount of fume released per ton of metal processed when poorer scrap was charged to the furnace. (The actual fume increase was over 40 percent since fumes evolved during a full quarter of the melting cycle were lost because of a defective collecting thimble.)

The rate of fume release appears to reach a peak during the boil and refining periods. When an oxygen lance is employed, dense fumes

Table 8. ELECTRIC-ARC STEEL FURNACE FUME DATA (Reference 11)

Case	Rated furnace size, tons	Average melting rate, tons/hr	Cycle time, hr	Fume formed per ton melted, lb/ton	Furnace process	Reference
A	50	18.3	4	9.3[a]	Basic, single slag	74, 75
	75	23.5	4	18.6[b]		
	75	23.5	4			
B	50[c]	14.4	4	7.6	Basic, single slag	76
	50[c]	13.6	4	6.9		
	75[c]	21.9	4	12.3		
	3	1.5	2	12.6	Acid, oxygen blow	
	3	1.1	2	7.6	Acid, oxygen blow	
	6	3.1		10.4		
	10	6.6	2	5.5	Basic, oxygen blow	
	10	5.4	2	5.2	Basic, oxygen blow	
	2[d]	1.5[d]		13.4		
C	3	1.9	2	4.5	Acid	77
	3	1.6	2	5.8	Acid	
	3	1.9	2	5.7	Acid	
	6	2.6	2.33	15.3		
	6	3.0	2	12.8		
D	18	5.4	3	6.1		78
E	6	4.1	1.2	29.4	Acid, single slag	79, 80
F	3	1.8	1.75	12.7	Acid, single slag	81

[a] Average for one 50-ton and two 75-ton furnaces processing normal scrap.

[b] Average for one 50-ton and two 75-ton furnaces processing dirty, sub-quality scrap.

[c] Refer to same furnaces as Case A.

[d] Two 2-ton furnaces operating in parallel.

of hematite and magnetite are produced.[12] As previously noted, this peak fume release is less pronounced when a mill-scale or a spontaneous boil is employed. It can be said in general that during refining, fume rates are high, reaching a final peak as pour temperature is approached.

In addition to the above factors, the effects of several other variables on total fume generation may be hypothesized, although not substantiated by experiment. The formulation of the charge may be a factor, the higher the proportion of subquality scrap contained in the charge, the greater the amount of impurities in the furnace. The impurities are, in part, subject to volatilization; hence, fume formation increases. Also, since the rate of heat flux to the bath increases in proportion to the rate of melt-down, higher temperatures exist in the molten pool when the higher melt-down rates are employed. The resulting increased temperature should cause greater over-all fume generation.

Nature of Pollutants

The effects on fume generation rate and chemical composition of the fume appear to be a function of the melting-cycle phase and the charge formulation and quality. Erickson[85] and Assel[84] have reported that fumes may analyze 40 to 50 percent iron oxide during melt-down. Erickson further states that when the scrap is completely melted the iron oxide content of the fume drops to well below 20 percent, with the remainder being composed of oxides of calcium, silicon, phosphorous, manganese, and sulfur. Assel also reports that after the slag is made up the iron oxide content may fall as low as 5 percent, with the calcium oxide content of the fume increasing to the 45 to 50 percent range.

In addition to the variations in fume composition resulting from melting-cycle phase, the effects of charge formulation and quality are significant. The inclusion in the charge of nonferrous metallic impurities results in the oxides of these metals being present in the fumes. Coulter[75] has reported the following average composition of fume produced during an entire melting cycle. It is likely that the charge contained an unusually high percentage of galvanized steel scrap.

Component	Weight percent
Zinc oxide (ZnO)	37
Iron (Fe)	25
Calcium oxide (CaO)	6
Manganese oxide (MnO)	4
Aluminum oxide (Al_2O_3)	3
Sulfur trioxide (SO_3)	3
Silicon dioxide (SiO_2)	2
Magnesium oxide (MgO)	2
Cupric oxide (CuO)	0.2
Phosphorus pentoxide (P_2O_5)	0.2

As noted, the composition includes a high percentage of nonferrous metallic oxides in addition to those constituents normally expected in the fume. Further substantiation that metallic impurities in the charge produce nonferrous oxides in the fume is found in the work by O'Mara,[31] who reports approximately 25 percent zinc oxide present in one such fume.

Certain physical properties are characteristic of the particulates from electric-arc steel-melting processes. Specifically, these particles have a strong tendency to adhere to both natural and synthetic fabric surfaces;[85] they possess a high angle of repose;[85] they are difficult to wet;[88, 89] and they posses a high electrical resistivity.[12, 85] These properties limit the applicability of control equipment, and specific consideration for offsetting these inherent properties of the fume must be provided for in satisfactory control installations.

Size distribution measurements by the Los Angeles County Air Pollution Control District[76] and by Erickson[85] (Table 9, Cases A and B) show that electric-arc steel furnace fume particles are predominantly (approximately 70% by weight) in the range below 5 microns. Electron photomicrographs[52] have shown that 95 percent by number of the particles in such fumes are less than 0.5 micron in diameter. The presence of appreciable percentages by weight of larger particles, as determined by sedimentation procedures,[76, 85] is undoubtedly due to the high agglomerating tendency of this type of fume.

Nitrogen oxides are emitted in small amounts. Ozone formed by the electric-arc is thought to be emitted, but no specific data were found. Sulfur gases are also probably emitted in fairly small amounts.

Table 9. ELECTRIC-ARC STEEL FURNACE FUME PARTICLE SIZE DISTRIBUTION IN WEIGHT PERCENT (Reference 11)

Size range, microns	Case		
	A	B	C
0 to 3			18
0 to 5	71.9	67.9	
3 to 11			64
5 to 10	8.3	6.8	
11 to 25			7
10 to 20	6.0	9.8	
>25			11
>20	13.8	15.5	
	100.0	100.0	100
Reference	76	85	88

Control Methods

The type of hooding provided in each melting furnace installation to collect fumes from the furnace and convey them into a duct determines the temperature and volume relationship of the effluent gas to be processed. Three types of control hoods are in general use: (1) canopy-type hoods, (2) enclosing or roof-ring hoods, and (3) direct furnace taps. Canopy hoods located above the crane-way offer the least interference with operating procedure; but to capture furnace effluent efficiently, large volumes of indraft air are required, resulting in lowered gas temperatures. Roof-ring hoods closely fit around the charging door, pouring spout, and electrodes and have a disconnecting flange in the exhaust duct to allow for furnace movement. A modification of this type of hood is the direct furnace tap in which the furnace itself serves as a refractory-lined hood. These last two types of hood require smaller volumes of indraft air for efficient collection, and higher effluent gas temperatures result.

The characteristically small particle size of electric-arc steel furnace fume precludes the use of dry centrifugal collectors, settling chambers, etc., when high efficiencies are required.

Furthermore, those types of control equipment capable of giving high-efficiency performance must operate within the following specific limitations: wet scrubbers require high power inputs, baghouse collectors need special provisions for increasing the effectiveness of the shaking mechanisms and for controlling the gas temperature and humidity, and electrical precipitators must have adequately conditioned gas.

High-efficiency scrubbing systems can be used for the control of electric-arc steel furnace fumes. However, high power requirements tend to negate their use. In one installation the fume collection system consists of a spark box, a washer, a disintegrator (a high-efficiency water-fume contactor), and a moisture eliminator.[90] A gas volume of 50,000 cfm at 60°F is handled with an inlet fume loading of 1.12 grains per cubic foot. The material, which is collected at 98 percent efficiency, analyzes just over 50 percent Fe_2O_3.

Use of an electrostatic precipitator to control fumes on one 50-ton and two 75-ton furnaces has been reported.[74, 75] The fumes are removed through direct furnace taps to a two-stage evaporative cooler-conditioner. The precipitator handles 105,000 cfm at 127°F with an inlet fume concentration varying between 0.68 and 1.35 grains per cubic foot. Collection efficiencies of over 97 percent are realized, and in the particulate concentration range concerned, should be relatively independent of inlet loadings.

A second electrostatic-precipitator installation although designed to employ gas conditioning actually does not because of a reduction in plant furnace capacity.[78] A ring-type hood directs the furnace effluent through a radiation cooler after which tempering air is added to reduce the gas stream temperature to 80°F. Approximately 33,500 cfm then enters the precipitator at this temperature with a fume loading of 0.115 grain per cubic foot. In this case, a collection efficiency of 92 percent is obtained, which as in the case above should also be relatively independent of inlet loading.

Fabric filters (baghouses) are used to control fumes from electric-arc steel furnaces. One such installation has been described by Dok.[88] It has Orlon fabric bags and handles 50,000 cfm of 124°F gas from one 1-ton, one 3-ton, and two 6-ton electric-arc steel furnaces. The total of roughly 40,000 cfm from the four furnaces is normally tempered with 10,000 cfm of cooling air to reduce its temperature to that required for baghouse operation. Efficiencies of greater than 98 percent are readily obtained.

Another baghouse handles a volume of 16,000 cfm at 130° to 180°F for a 6-ton acid furnace.[79, 80] The furnace employs single-slag operation with an oxygen lance during the boil. No specifically designed gas cooler is in use, but a long duct run serves as an effective radiation cooler. Actual efficiencies have not been measured but are assumed to be 98 percent or better. Cotton bags rotted after only short usage and have been replaced with Orlon bags. The deterioration of cotton is probably caused by the presence of ozone and oxides of nitrogen, in addition to the acidic nature of the gas.[91]

A third baghouse operation processes the effluents from a 3-ton furnace in which an acid, single-slag melting cycle is used in combination with a mill-scale boil.[81, 92] The gas passes through an enclosed roof hood and then is cooled by radiation and air tempering to 142°F before it enters the baghouse. The bags are of Orlon fabric. About 12,000 cfm are cleaned at an average inlet loading of 0.22 grain per cubic foot. Collection efficiencies of over 99 percent are reached.

Although data collected are incomplete, indications are that approximately 40 electric-arc furnaces at iron and steel mills have been equipped with air pollution control devices.[73] The largest number are using baghouses. Electrostatic precipitators, venturi scrubbers, and other high-energy dynamic scrubbers are also used. There are many electric-arc steel furnaces that are not located at iron and steel mills. There are about 301 furnaces at iron and steel works. The 40 with air pollution controls comprise about 13 percent of the total.

BESSEMER CONVERTERS

Bessemer converters are not extensively used. Only about 2 percent of the Nation's total steel is produced in these units.

Rate of Pollutant Generation

An average Bessemer converter is rated at 20 to 35 ton per heat with two or three cycles per hour.[31] The rate of emission from a 25-ton converter with a 10- to 15-minute blow has been estimated to be 10 grains per cubic foot, or between 15 and 20 pounds per ton of steel produced.[40, 45] A 25-ton converter operating two cycles per hour and emitting 20 pounds per ton of steel produced would emit a total of 12 tons per day. Lower grain loadings of 0.15 to 0.4 grain per cubic foot have been reported in the case of an oxygen-blown 20-ton basic converter, with sampling being carried out at some distance from the vessel throat.[93] Other test work indicates dust loadings in the order of 0.8 grain per cubic foot.[31]

Data from German experiments have been reported for a 30-ton converter.[5,94] Dust measurements indicated an average emission of solids of 132 pounds per minute or 1320 pounds for a 10-minute melt (44 lb/ton of steel). These emission figures include all the very coarse materials, a major portion of which would would settle out rapidly on the premises immediately surrounding the installation.[5]

During the operating cycle the volume of gas emitted varies from near zero during the non-blow periods to about 2 million cubic feet at 2700° to 3500°F during a 10- to 15-minute blow.[40,45] The rate of dust emission would also vary considerably throughout the cycle. It has been stated that fume emissions increase very considerably when an oxygen enriched blast is used,[40,93] but the use of an oxygen-steam blow is said to reduce fume production to about the same level as that experienced with air blowing.[40]

Nature of Pollutants

The Bessemer flame, which may reach 30 to 40 feet in length, contains carbon monoxide that is rapidly burning to carbon dioxide, plus two kinds of particulate matter. Pellets of molten metal and slag are mechanically ejected by the violence of the air blast bubbling through the molten bath. These are known as spittings, composed, as they are, of relatively coarse particles that tend to settle out on the premises close to the source. The other type is the visible orange-colored fume of iron oxide, resulting from volatilization in the converter of some of the iron and its subsequent oxidation in the open air. These small particles are suspended in the hot gases, which because of their buoyancy rise to great heights, transporting the visible fume with them.[5] It has been reported[5,94] that about three-fourths of the particulates, by weight, are larger than 100 microns.

The pellets, which are spit out, rise to a height of 50 or 60 feet. When they impinge upon a solid object, such as a wall, girder, or roof, they flatten and stick much like a metal spray. In time, heavy masses of iron and steel are formed and unless removed, they drop off and endanger those who are working below.[5]

Measurement of air velocities and of temperatures in the plume at a distance of 55 feet from the converter mouth indicated that the total flow of flue gas (including the air that had become turbulently entrained in the 55-ft distance) amounted to 250,000 to 300,000 cfm at temperatures between 450° and 550°F. This is the gas volume that must be subjected to gas cleaning.[5]

Control Methods

None of the Bessemer converters presently in use in the United States is known to be controlled. The primary difficulty in adapting control devices to converters is confinement of the effluent. Normal operating procedure, plus the spitting action of the process, precludes the installation of a control device near the mouth of the converter.

Research and Development

The American Iron and Steel Institute (AISI), during the last several years, has been sponsoring a research program at Battelle Memorial Institute aimed at preventing the formation of iron smoke at its source, thus obviating the need of collecting it.

The initial specific objective of the AISI research program was to discover practical methods of reducing, to unobjectionable levels, the emission of smoke and dust from steel conversion by the Bessemer process.[95] It was believed from the outset that if the emissions could be eliminated from this process the knowledge could be extended to suppression of smoke emissions from all steel-making processes. In this research, operating converters were studied. Thereafter, a 300-pound experimental converter was operated to simulate the commercial Bessemer converter. With this converter, hydrogen, methane, or ammonia added to the blast gas suppressed smoke. From a practical standpoint, it appears that the possibility of adding methane to suppress smoke in Bessemer converters has merit and seems worth trying in a field test.

More recently, the AISI research program was modified to direct the objective at the determination of the mechanism by which iron smoke is formed. Once the mechanism is known, it should be possible to devise methods of suppressing smoke or at least controlling the physical characteristic of the smoke so it can be removed readily.

The first step toward understanding the fundamentals of iron smoke formation was to establish the separate effects of temperature, metal composition, blast gas composition, and other external variables on the formation of smoke. Simultaneously, details of possible smoke-forming reactions were analyzed thermochemically. Combining these approaches has led to a much improved understanding of the mechanism of smoke formation and possible practical methods of reducing the amount of particulate matter from both top-blown and bottom-blown steel-making processes.

BASIC OXYGEN FURNACES

Rate of Pollutant Formation

The average basic oxygen furnace in the United States in April 1961 had a capacity of about 100 tons per heat. Only a year or so earlier the average would have been about 60 tons per heat, but at the rate that large furnaces are being installed,[15] 100 tons per heat may soon be outdated. If this furnace completed one heat cycle per hour, it would generate on the order of 1 to 2 tons of dust and fume per hour (25 to 50 tons per day).[14,29,96] This represents 1 or 2 percent of the steel produced. At the Donawitz plant in Austria, a basic oxygen furnace rated at 30 tons per heat generates 35 to 60 pounds of dust per minute during the blow.[40,70,97] This is equivalent to 13 to 23 tons per day, if blowing oxygen takes one-half of the heat cycle, or equivalent to 2 or 3 percent of the steel produced.

Dust loadings in the waste gas are reported to be about 7 to 8 grains per scf at a plant in Canada.[29,49] Control equipment designers in this country have used a value of 5 to 5.2 grains per scf.[73]

The major operation causing dust and fume generation is oxygen blowing. Other steps in the heat cycle are relatively minor contributors. The waste volume produced from oxygen blowing is not necessarily related to the nominal tonnage rating of a vessel. Instead it is proportional to the blowing rate. By plotting design oxygen blowing rates versus exhaust gas volumes for systems both presently in service and proposed, Gaw[96] arrived at a design volume rating of 25 scfm of waste gases per cfm of oxygen blown. He found that the ratio for venturi cleaning systems often was slightly less at 20:1. These ratios take into account the excess dilution air drawn into the system. Dilution air is desirable to reduce the explosion hazard and to allow proper control of the temperature of combustion products.

Nature of Pollutants

The composition of gases emitted from a basic oxygen converter, after ignition above the furnace, are reported as follows,[96] in percent:

Carbon dioxide (CO_2)	0.7 to 13.5
Oxygen (O_2)	11.1 to 20.0
Nitrogen (N_2)	74.5 to 78.9
Carbon monoxide (CO)	0.0 to 0.3
Illuminants	0.0 to 0.2
Hydrogen (H_2)	0.0 to 0.4

Chemical analysis of dust and fume arising from a basic oxygen furnace is as follows,[96] in percent:

Iron oxide (Fe_2O_3)	90.0
Manganous oxide (Mn_3O_4)	4.4
Ferrous oxide (FeO)	1.5
Silicon dioxide (SiO_2)	1.3
Calcium peroxide (CaO_2)	0.4
Phosphorous pentoxide (P_2O_5)	0.3
Aluminum oxide (Al_2O_3)	0.2

During large-scale testing of various gas-cleaning systems on the Donawitz plant in Austria, several dust samples revealed that the Fe_2O_3 content increased with decreasing particle size.[97] At Donawitz, approximately 40 percent of the dust particles, by weight, were less than 5 microns with the 1- to 2-micron size predominating.[97] An investigator in the United States reports particle size to be somewhat smaller, as follows:[96]

<0.5 micron - 20 percent
0.5 to 1.0 micron - 65 percent
1.0 to 15.0 micron - 15 percent

Control Methods

All 12 basic oxygen furnaces operating in this country as of January 1, 1960, were equipped with high-efficiency control devices. The furnaces are all relatively new and were equipped with air pollution control equipment when built. This practice is also common in foreign countries. The gas-cleaning systems are divided between high-pressure-drop venturi scrubbers and electrostatic precipitators. The wet system has the disadvantages of high operating horsepower requirements and need for water clarification. Electrostatic precipitators have a potential explosion hazard and a dust disposal problem. Still, these are the only systems that have been found satisfactory. This was determined at the Donawitz plant in Austria through 509 experiments on eight different dust-collecting systems.[97] Gaw has reported on the advantages, costs, and maintenance of electrostatic-precipitator and venturi cleaning systems.[96]

Dust and fume control facilities are very expensive to install and operate. Depending on a number of factors pertaining to specific establishments, some operators, particularly those in Europe, believe it may be possible to defray a part of the costs through use of waste-heat boilers for cooling of gases in the dust-collecting system and by returning the collected dust to the process, after suitable preparation.[73, 96, 97, 170]

Final effluent from these control devices will contain around 0.05 grain per scf. A venturi system is reported to discharge to the atmosphere about 0.03 to 0.09 grain per scf, with a maximum of 0.12,[49] varying with furnace operating conditions and pressure drop across the venturi throat.

MISCELLANEOUS OPERATIONS

There are several miscellaneous sources of air pollution in the steel-making industry, such as heating and reheating furnaces, scarfing machines, power plant boilers, slag dumps and crushers, and rail locomotives. Although their individual significance as air pollution sources may be relatively minor in comparison with some of those discussed previously, when taken collectively they may prove important if suitable attention is not given to air pollution control.

Heating and Reheating Furnaces

With the almost universal use of instruments and automatic combustion controls, modern furnaces seldom emit black smoke. However, in the earlier days of the industry when the technology of furnace design was less well understood, there were frequent instances of smoking chimneys due to lack of automatic fuel-air-ratio controls and to insufficient combustion space, with the result that the fuel gases were incompletely consumed before coming in contact with the relatively cold steel, and black smoke resulted. Some of the older heating and reheating furnaces of poor design are still in operation but are rapidly becoming obsolete and being replaced with modern units.[5] The principal pollutants emitted from properly designed and operated furnaces are the normal gaseous products of combustion and perhaps particulate matter, the amount and characteristics depending on the type of fuel used. There also are times when too much fuel is fed into a furnace containing cold metal, resulting in emission of smoke.

Scarfing

Information is very meager on pollutants generated in scarfing operations. Spot tests on a 45-inch slabbing mill and a 40-inch blooming mill indicated dust loadings of around 0.4 grain per scf.[39] One investigator found a stack loading of about 0.22 grain per cubic foot in an effluent volume of 36,840 cfm from a 32-inch slabbing mill and from 0.42 to 4.4 grains per cubic foot in an effluent volume of 87,000 cfm from a 53-inch slabbing mill.[43] An effluent of 50,000 cfm containing 0.4 grain of dust per scf, if uncontrolled, would discharge over 2 tons of dust per day. This is probably conservative since the fume loading from scarfing machines has been accepted in some cases as 0.8 grain per scf.[70] Gas volume ranges from 20,000 cfm for the lightest two-edge table to 150,000 cfm for the heaviest four-side machine.

Fine material produced in scarfing operations amounts to approximately 36 grains per pound of metal removed, and in typically heavy duty scarfing operations, this may amount to 50 to 75 pounds of solids per hour.[5]

The use of air pollution control equipment on this process would be desirable. The extent of use in the industry was not determined. Many plants use a baffled settling chamber that collects large particulates. One such installation collects 7000 to 9500 pounds of iron oxide and other dust per week.[98] The cleaners collect approximately 2 pounds of dust per ton of steel processed.

Power Plant Boilers

Emissions from boilers might include smoke and flyash, plus varying amounts of gaseous pollutants (sulfur dioxide, nitrogen dioxide, etc.). In general, particulates may be controlled by standard techniques (cyclones, precipitators, etc.). Control of gaseous pollutants from such operations is not practiced at steel mills nor at any fuel-burning installations, except for use of low-sulfur fuels at some plants, as an air pollution control measure.

Slag Dumps and Crushers

Dust generated at slag dumps and in crushers, as well as in other materials-handling operations, are commonly suppressed by ordinary methods. However, if the dust from these operations is not controlled, it may cause severe local nuisance problems.

Rail Locomotives

Nearly all mills have diesel-powered railroad engines to handle material transfers and finished-product movement. A few coal-fired engines may still be in use. Rail transportation is used to move raw materials such as coal, iron ore, and limestone from storage points, where processing begins; to move intermediate products such as coke and pig iron to subsequent processing points; and to move finished products from the manufacturing area to warehouse facilities. The primary emissions from coal-burning locomotives are smoke and flyash. The usual gaseous products of combustion are also emitted. Diesel locomotives emit some small-size particulate matter and gaseous pollutants, but they are insignificant in comparison to other steel mill emissions.

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Part IV

EFFECTS OF AIR POLLUTANTS FROM IRON AND STEEL WORKS ON THE COMMUNITY

NEIGHBORHOOD AIR QUALITY STUDIES

Pollutants in a community atmosphere may arise from many sources including industrial plants, automobiles, burning dumps, home heating plants, commercial operations, and backyard trash burners. Larger particles (larger than say 5 microns in size) settle from the atmosphere and cause soiling of automobiles, porches, window sills, laundry, vegetation, furniture, rugs, goods on shelves in stores, etc. These larger particles tend to settle out of the atmosphere close to their point of emission. Smaller particles (smaller than say 5 microns in size) attach themselves to all sorts of objects and cause soiling of house paint, curtains and drapes, building stone, windows, merchants' stocks, etc. They also decrease beneficial sunlight and cause a gloominess in the community atmosphere. They tend to travel great distances from their point of emission. Gaseous pollutants may cause offensive odors, deterioration of materials, and damage to vegetation. Beyond these effects, air pollution, in general, in certain areas (especially in major cities) is a hazard to man's health.

As background information for use in judging significance of pollution levels reported later herein, some typical values will be useful. Pollution levels several times higher than the "typical" values occur from time to time in some cities. Lower pollution levels also occur. Dustfall in suburban areas of large cities are often around 10 or 15 tons per square mile per month. Central parts of large cities may experience 30 to 60 tons per square mile per month. Values above 25 are considered undesirable from a community welfare standpoint by some authorities. Suspended particulate matter (on a weight basis) ranges from an average of 40 micrograms per cubic meter of air in non-urban areas to more than 2500 in highly polluted areas, on particular days. Long-term average values for cities having 700,000 to 1,000,000 population, at locations in the central part of town, are around 144 micrograms per cubic meter of air. Cities having 100,000 to 400,000 population experience an average of about 120 micrograms per cubic meter of air. Values for the soiling power of suspended particulate matter range from near zero with a clean atmosphere to more than 10 Cohs per 1000 linear feet for a disagreeably smoky day.[99] One authority classifies values from zero to 0.9 Coh per 1000 linear feet as light smoke, from 1.0 to 1.9 as moderate, from 2.0 to 2.9 as heavy, from 3.0 to 3.9 as very heavy, and 4.0 or more as extremely heavy.[100] Average values for a reasonably clean city would be around 1.0 or less on an annual basis. Sulfur dioxide values range from near zero in small communities to more than 5 ppm in the vicinity of major sources for short periods. General average values for the central parts of large cities (1,000,000 population or more) might be around 0.03 to 0.06 in the summer and 0.03 to 0.25 in the winter, depending on fuels burned in the area, industrial activity, pollution dispersion, etc. The minimum detectable by the sense of smell is 3.0 ppm and by sense of taste, 0.3 ppm. Some species of vegetation are damaged by concentrations of 0.3 ppm, if the concentration persists for a number of hours. Sulfur dioxide values, as indicated by lead peroxide candles, may exceed 4.0 milligrams SO_3 per 100 square centimeters per day during the winter in the central parts of fairly heavily polluted cities. In the summer values are around 1.0 milligram SO_3 per 100 square centimeters per day. In the residential suburbs of such a city, these values are around 0.4 in the summer and 1.0 in the winter. Higher values would be expected near large sources of sulfur dioxide pollution.

All values reported later herein must be considered in the light of changes that occur in meteorological conditions. The wind seldom blows in a certain direction continuously. Thus, for a fixed sampling station, emissions from a given source may be carried to the station for only a small part of an hour, a day, or a month. The values reported represent average conditions at a point during the sampling period. No doubt large variations occur that cause instantaneous pollution concentrations to be many times greater or many times less than the average.

Studies Made in the United States

During the 1956 steel strike, pollution measurements were made in four steel-producing areas, for comparison with similar measurements made after the steel mills resumed operation.[101] Tests were made during July and August, at which time pollution from space heating plants was not involved. Certain other activities that may cause pollution also are curtailed or shut down during steel strikes. Thus, the change in pollution levels from the strike period to the post-strike period was due to the total effect of rate of pollutant emissions from all activities. Sampling stations were located from 1/8 to 1 mile away from steel mills. Suspended particulate pollution during the post-strike period was higher by 44 to 171 percent than during the strike, varying from one city to another. Average suspended particulate levels ranged from 183 to 279 micrograms per cubic meter in the four areas during the post-strike period. Sulfur dioxide pollution measured in one area did not vary, from the strike period to the post-strike period, indicating that the steel mills did not cause major pollution by this gas. The soiling power of suspended particulate matter measured in one community was twice as great during the post-strike period as it was during the strike period, indicating that the steel mills (and other activities discontinued during the strike) are a significant source of this type of pollutant. Average post-strike values were 1. 2 Cohs per 1000 linear feet, with 8 percent of the values being greater than 2. The concentration of iron in suspended particulate pollutants during the post-strike period was 2. 6 to 10. 8 times greater than during the strike period, indicating that the steel mills are an important source of this pollutant.

A study was made in 1950 in a northern Ohio city during periods when the steel mills were shut down because of a labor strike and for a comparable period after operations were resumed.[102] Mean sulfur dioxide concentration during the strike period was 0. 034 ppm, with one sample in the range 0. 29 to 0. 39 ppm. During the post-strike period the average was 0. 050 ppm, with one sample in the 0. 39 to 0. 49 ppm range; however, this increase was not considered statistically significant. Measurements of fluorides were practically the same during the strike and post-strike periods. The soiling value of airborne dust, as indicated by shade or darkness of deposits on filter papers, was 50 percent greater during the post-strike period than during the strike. These data indicate that operation of steel mills in this city considerably increased suspended particulate matter, which causes soiling, and had a minor effect on sulfur dioxide concentrations, but no demonstrable effect on fluoride concentrations.

A 1-month study has been made of air pollution in the upper Ohio River Valley area.[103] There are two major steel mills, two large coke plants, steam-powered electric-generating plants, and other industries in the area. Sampling stations were located in the immediate neighborhood of major spurces of pollution. Dustfall was 566 tons per square mile per month near a steel mill, and 123 at another site. Total suspended particulate matter averaged 383 micrograms per cubic meter of air in one city and 186 in another. A maximum of 1238 micrograms per cubic meter was observed in one community, and one suspended particulate matter sample from that city contained 30. 8 micrograms of iron per cubic meter of air. Soiling values averaged 5. 5 and 5. 3 Cohs per 1000 linear feet in two cities. Although other sources contribute to pollution in this valley area, the data demonstrate the high pollution levels that may be found in the immediate area of some iron and steel works.

As part of a generalized study of the occurrence and sources of benzo(a)pyrene as an air pollutant, a short-term study was done in an upper Ohio River community in late March and early April 1961.[166] Forty-eight-hour (approximate) samples were collected in high-volume filter paper samplers at four locations for a period of 12 days. Sampling sites were about 1-3/4 miles from a large, integrated steel mill with many coke ovens. Three of the four sampling stations were on hills, at an elevation of about 1000 to 1100 feet above sea level. One was located in a valley, at about 680 feet above sea level, the approximate ground elevation at the steel mill. Total weight of suspended particulate matter in the air ranged from 23 to 189 micrograms per cubic meter and averaged between 69 and 142 for the four stations; the highest station average (142) was at the station in the valley. None of these data indicated grossly excessive suspended particulate pollution. Benzo(a)pyrene concentrations for composite samples for the 12-day period at each station ranged from 0.006 to 0.01 microgram per cubic meter of air. Similar concentrations of benzo(a)pyrene are also found in many cities of the country.[112] The amount of benzene soluble organic matter in the samples ranged from 2.0 to 11.5 micrograms per cubic meter and averaged 6.7. Such values are in the same range as those reported for the air over many cities.[167] Concentration of certain metallic ions were determined in each of the four samples. Although little significance can be attached to this small number of analyses, it was found that concentrations of iron, manganese, titanium, chromium, cadmium, and antimony were above the average found in many cities.[167] Concentrations of lead, copper, vanadium, zinc, and nickel were below the averages found in many cities.

In one Pennsylvania town, industrial development was dominated by a steel and wire plant, and a zinc plant. The steel mill, in 1949, consisted of two blast furnaces, eleven 110-ton open hearth furnaces, a sintering plant, and other equipment. There were also a coke plant and two steel plants at another city a few miles away. Measurements made between February 16 and April 27, 1949,[104] gave the distribution of values for suspended particulate matter shown in Table 10. Station 9 was 300 yards from the open hearth shop; station 10 was 800 yards from the open hearth shop and about 2 miles from the steel mill in the neighboring city; station 11 was 600 yards from the blast furnaces and 500 yards from the open hearth shop; and station 12 was 70 yards from the open hearth shop and 800 yards from the blast furnaces. Although average values are not given, the number of samples containing more than 500 micrograms per cubic meter (22 out of 53) indicate very high pollution levels. Other sources contributed to pollution present, but there is little doubt that the steel mill made a sizeable contribution. High levels were found in April when use of fuel for space heating by domestic and commercial establishments was at a relatively low rate.

Table 10. TOTAL SUSPENDED PARTICULATE MATTER IN A PENNSYLVANIA CITY NEAR A STEEL MILL (1949) (Reference 104)

Concentration[a] $\mu g/m^3$	Number of measurements in the range indicated				
	Station 9	Station 10	Station 11	Station 12	All four
0 to 400	8	8	9	6	31
500 to 900	3	3	4	6	16
1000 to 1400	1	1	0	0	2
1500 to 1900	1	0	0	1	2
2000 to 2400	0	1	0	0	1
2500 or more	0	0	0	1	1

[a] Two-hour samples.

An extensive study has been made of air pollution in a large Michigan community. In 1951,[105] suspended particulate matter was measured at 31 stations. At one station near two coke plants, iron and steel foundries, a blast furnace, and many other industries, suspended particulate matter concentrations in the air averaged 343 micrograms per cubic meter over a 5-week period. Iron content of suspended particulate matter averaged 5.8 micrograms per cubic meter. During the same period, in a residential area, total suspended particulate matter averaged 122 and iron content of suspended particulate matter averaged 0.6 micrograms per cubic meter of air. Dustfall measured from 1951 through 1953[106] averaged 116 tons per square mile per month in the industrial area while in a residential area it averaged 34. The high pollution levels were not due to iron and steel operations only, but there is little doubt that these played an important part in causing the high levels.

Processing of blast furnace slag may cause pollution in the surrounding neighborhood. The operation usually consists of moving slag from the blast furnace to a dump. After cooling, the slag is segregated, crushed, classified by screening, and loaded for shipment. Dustfall in and around a small community (500 population), resulting from operation of one such plant where some steps had been taken to control emissions, has been reported.[110] Even with some controls in use, it was estimated on the basis of analyses of collected dust that from 5 to 109 tons of dustfall per square mile per month at stations located about 0.4 miles from the plant resulted from blast furnace slag processing. The variation was due to relative prevalence of wind directions, specific station location, and other factors. Suspended particulate samples were also collected at one station located 0.4 miles from the plant, and often downwind from it. Loadings ranged from 124 to 1980 micrograms per cubic meter of air, and averaged 411. At another station located 0.8 miles from the plant, and in the same direction from the plant as the other station, concentrations averaged 195, with a maximum of 477. While other pollution sources contributed to these pollution levels, chemical analyses indicated that 35 to nearly 100 percent of the suspended dust at stations 0.4 miles downwind from the plant came from blast furnace slag processing.

Studies Made in Foreign Countries

Studies made in foreign countries may not be applicable to the United States situation, since different equipment, materials, and processes may be used. Also, equipment may be in a different state of repair, and operating practices may be different.

A detailed study of dustfall rates in the vicinity of an integrated iron and steel works was made in England in 1955, 1956, and 1957. Measurements were made at 64 stations both on the grounds of the mill and in the surrounding neighborhood.[107] On the plant premises, dustfall rates from 250 to 500 tons per square mile per month were found. Values decreased to about 50 tons per square mile per month at distances of 1/2 to 3/4 mile from the plant. In the same study, sulfur dioxide was measured by the lead peroxide candle method at 30 stations. Measurements were made during the summer months when space heating units were not in operation. Values were about 1.0 milligram of SO_3 per 100 square centimeters per day at a distance of about 1/2 mile from the plant and increased to about 2.0 on the plant premises. The data indicate that emissions from the plant cause excessive dustfall in the neighborhood of the plant and make some contribution to sulfur dioxide pollution levels.

Measurements of dustfall in the Ruhr district of Germany in the vicinity of a steel mill[108] indicated dustfall rates of 42 to 133 tons per square mile per month at locations within 1/2 mile of the mill, varying with specific sampling location, wind direction, etc.

Suspended atmospheric dust was measured at a number of locations in Belgium by exposing vaseline-coated aluminum spheres 12 centimeters in diameter.[109] Average values for the amount of dust collected were 1.5 milligrams per day in the country, 6 in the central parts of cities, and 20 in the neighborhood of a coke plant. These data indicate that the air near a coke plant contains more than 3 times as much dust (of the type collected by this instrument) as the air in the central parts of cities.

Measurements of benzo(a)pyrene were made in the neighborhood of a Russian pitch-coke and coke-chemical plant of obsolete construction. Concentrations of 0.002 to 0.4 milligram per cubic meter were found on the plant grounds.[111] The plant was modernized and pollution emissions brought under a measure of control. Benzo(a)pyrene values dropped to 0.0004 milligram per cubic meter. There was not sufficient information given in the paper to evaluate significance of the data; however, a value of 0.00005 milligram per cubic meter is considered relatively high for the general atmosphere of polluted cities,[112] indicating that the plant investigated was a substantial source of this pollutant. It is generally accepted that destructive distillation of coal results in formation of benzo(a)pyrene and a number of other similar materials.

The concentration of phenol in the air has been measured in the area surrounding a large coke-chemical plant in a Russian community. The "characteristic odor of coke-chemical plants" was clearly perceptible to all points within 1.86 miles of the plant.[42] Maximum concentrations of 0.8 ppm of phenol were found within 0.6 mile of the plant and 0.3 ppm at a distance of 1.86 miles. The odor threshold of phenol is less than 0.9 ppm and may be as low as 0.05 ppm. (There are conflicting reports on the odor threshold of phenol.) Thus, people living in an area of 1 to 3 square miles may be, from time to time, bothered by odors of phenol from the plant under study. The "characteristic odor of coke-chemical plants" would, from time to time, be detectable by people residing in an area of about 3 square miles surrounding this plant.

RELATIVE MAGNITUDE OF IRON AND STEEL MILL EMISSIONS

As a means of developing a concept or feeling as to the magnitude of emissions from various operations at iron and steel works and to relate these to emission of pollutants from other sources,

Table 11. EXAMPLES OF PARTICULATE POLLUTION EMISSIONS FROM IRON- AND STEEL-MAKING OPERATIONS AND OTHER POLLUTION SOURCES[a]

PARTICULATE EMISSIONS FROM IRON AND STEEL MAKING OPERATIONS

Name of equipment and its capacity	Air pollution control equipment; exit gas grain loading; and other conditions assumed	Emission from described operation, lb/day	Approximate emission with best available control, lb/day
BYPRODUCT COKE PLANT 250 ovens. 5, 100 tons of coal used per day. 3, 560 tons of coke produced per day.	No special equipment. 0. 1 % of coal used emitted as solids (estimated). Reasonably good practice.	10, 200	b
SINTERING MACHINE 1, 000 tons of sinter produced per day in one machine.	Cyclones clean 140, 000 scfm of combustion gases to 0. 2 gr/scf.	5, 800	1, 400
	Cyclones clean 15, 000 scfm of gases from belt discharge enclosure to 0. 4 gr/scf.	1, 200	200
BLAST FURNACES Four units each producing 1000 tons per day.	Preliminary cleaners and wet scrubbers handle 87, 000 scfm per furnace. Exit loading 0. 3 gr/scf.	21, 500	3, 600
OPEN HEARTH FURNACES Thirteen furnaces, each with 175-ton rated capacity. No oxygen roof lances.	No control equipment. 25, 000 scfm per furnace. Average exit loading is 0. 4 gr/scf.	26, 800	5, 100
ELECTRIC-ARC FURNACES Two furnaces with 50-ton rated capacity each. Five heats per day.	No control equipment. Loading 0. 43 gr/scf in 30, 000 scfm for each furnace.	5, 250	600
SCARFING MACHINE One 45-inch, four-sided machine.	No control equipment. Loading 0. 4 gr/scf in 85, 000 scfm.	7, 000	900

PARTICULATE EMISSIONS FROM OTHER SOURCES

Pollution source	Particulate pollutants emitted, lb/day
5, 000 homes burning coal; average winter day; northern city.	3, 780
50, 000 homes burning fuel oil; average winter day; northern city.	6, 000
50, 000 homes burning refuse in open fires.	4, 400
Refuse from 100, 000 homes burned in municipal incinerators.	3, 520
300, 000-kw coal-fired electric power station; good dust collectors.	11, 000
300, 000-kw coal-fired electric power station; fair dust collectors.	40, 000

[a] Values estimated by present authors based on data in this report and on published emission data concerning sources of pollution other than iron- and steel-making processes.

[b] No estimate of probable reduction available.

a tabulation has been prepared (Table 11). The nature and magnitude of the individual iron- and steel-making operations selected for comparison may be found at some mills, although wide variations exist. Emissions of particulate matter only are tabulated since these are of greatest concern in the case of iron and steel works. Application of available means for control of emissions from iron and steel mill operations would bring about a major reduction even though the equipment selected and listed in Table 11 was taken to include certain air pollution control equipment.

It can be seen that particulate emissions from the selected iron and steel mill operations are sizeable in comparison with certain other sources of particulate pollutants. For example, emissions from the 13 open hearth furnaces without air pollution control equipment are roughly equivalent to particulate emissions from about 35,500 coal-fired home-heating plants. Particulate matter emissions from the sintering machine having only cyclones for air pollution control would be roughly equivalent to particulate matter that would be released to the atmosphere if about 66,000 home owners burned their refuse in open fires. Table 11 can be used to make other comparisons. It is apparent that an iron and steel mill could be responsible for a sizeable part of the total particulate matter discharged to the atmosphere of a community. As indicated by emissions from a large pulverized-coal-fired, steam-powered, electric-generating station, however, other major sources may also play a substantial role.

ESTIMATED EFFECT OF USE OF OXYGEN LANCES IN OPEN HEARTH FURNACES ON COMMUNITY AIR QUALITY

It is generally agreed that injection of oxygen into open hearth furnaces through lances installed in the furnace roof increases the amount of dust and fume discharged from the furnace into the atmosphere. The question arises as to the effect this increased emission has on air pollution levels in the surrounding neighborhood. Since no field measurement data are available to help answer this question, estimates have been based on calculations in which atmospheric dispersion theory and reasonable assumptions of meteorological and plant-operating conditions were used.

In these estimates, it was assumed that there was one open hearth with a stack 150 feet high and 5 feet in diameter at the top. Furnace discharge rate was taken as 79,800 cfm at 1200°F (25,000 cfm at 60°F). Particulate loading in the exit gases was taken as 0.4 grain per scf for the regular open hearth and 0.6 for the furnace with oxygen lances. The dust and fume was considered to have a mean particle diameter of 0.5 micron and a particle density of 5.2 grams per cubic centimeter. The particle size distribution given by Bishop et al.[57] (see earlier herein) was used. Meteorological conditions assumed were: wind speed 11.2 mph; air temperature 59°F; air pressure 29.2 inches of mercury; air density 1.1945 kilograms per cubic meter; atmospheric diffusion coefficient 0.12 $m^{n/2}$; and a turbulence parameter of 0.25. The height of rise of the plume above the stack, calculated by Holland's equation,[113] was 88.5 feet; thus, the particles were carried to about 240 feet above ground before being dispersed. This effective stack height was used in the calculations.

Deposition of open hearth dust in the surrounding neighborhood (dustfall) results from both fallout and diffusion, the latter being the most significant for small particles. For both fallout and diffusion, the deposition rate at various distances from the stack was determined along an imaginary line downwind from the stack. Total deposition rate was obtained by adding fallout and diffusion. Deposition at certain distances downwind from the stack and at various distances away from the center line of the plume were also computed by use of the crosswind diffusion component of Sutton's equation.[113] Airborne particulate matter concentrations at ground level and the distance from the stack to the point of maximum concentration were computed from atmospheric diffusion equations.[113]

Based on results of these calculations, several conclusions were drawn:

1. Diffusion is especially important in dispersion of the very fine particles emitted by an open hearth furnace, whether oxygen lances are used or not. Only about 6 percent of the total emission falls to the ground within a mile of the stack. The bulk of the material is still airborne at that point.

2. The most important effect of using oxygen lances in the furnace is that ground level concentrations are increased at all points in the neighborhood of the plant. The increase in community pollution levels is in direct proportion to the increase in emissions. Therefore, use of oxygen lances increases average pollution concentrations 50 percent, over those from furnaces operated without lances, providing both types of furnace are operated continuously. At the point of maximum concentration of airborne particulate

matter from the furnace under consideration, concentrations would be 95 micrograms per cubic meter of air for a regular furnace and 142 for a furnace with oxygen lances. The point of maximum concentration occurs about 5000 feet from the stack under the conditions given above.

3. Dustfall in the community surrounding the furnace are appreciable, even though most of the particles tend to remain airborne. One open hearth stack causes a dustfall rate of 10 tons per square mile per month or more for a distance of 2 miles downwind from the stack if oxygen is not used, and for a distance of nearly [illegible] miles if oxygen lances are used. For purposes of comparison, dustfall rates in suburban areas from all sources of pollution is often about 10 tons per square mile per month.

The average steel mill has about 12 open hearth furnaces. The foregoing was based on a single furnace. Operation of more than one furnace of course increases pollution in the surrounding community; however, the relative increase at ground level would be somewhat less than the relative increase in emissions from additional stacks.

In the air pollution levels calculated above, a constant wind direction was assumed. The pollution level estimates are correct for a specific moment, but they would not be representative of longer time periods, such as 30 days for dustfall and 24 hours for suspended particulate matter. The wind direction that will carry pollution from a source to a certain location in the neighborhood may occur about 15 percent of the time over a long period. Thus, the pollution levels estimated above would be 6 or 7 times too high. However, since they are based on a single furnace whereas the average open hearth shop has 12 furnaces, the estimates are probably representative of average neighborhood pollution from the operation of an open hearth shop.

Pollution levels were estimated on the basis of "average" atmospheric dispersion conditions. Actually, during the daytime stack plumes spread laterally and vertically with a decrease in average concentrations, whereas night conditions often stretch out the plume and cause concentrations higher than those given. Generally, either daytime or nighttime conditions prevail rather than "average" conditions.

Iron and steel mills usually include many sources of pollution other than open hearth furnaces. Thus, the percentage increase of emissions from the plant as a whole that would occur if oxygen roof lances were to be added to the open hearth furnaces would be reasonably small, perhaps in the neighborhood of 10 to 15 percent.

EFFECTS OF FLUORIDES FROM CERTAIN IRON AND STEEL WORKS ON VEGETATION AND ANIMALS

Two steel mills in the western part of the country have been associated with neighborhood air pollution problems caused by the fluorides emitted. The fluoride emission was largely due to the higher-than-average fluoride content of the iron ore processed and to a limited extent to fluorides in fluxes used. These high-fluoride ores are used by very few mills. Fluxes are used by most mills, but have not caused a recognized problem. The problem has been accumulation of fluorides in certain species of vegetation. This has resulted in damage to certain vegetation, and cattle have been injured from eating contaminated forage.

In the case of one of the mills, claims have been made and settled for damage to cattle and for some damage to small fruits (apricot and plum). There have also been some limited nuisance claims for ornamental and other crops. In the case of the second mill, the claims were chiefly for damage to grape and citrus with limited claims for damage to other agriculture products.

Part V

PUBLIC HEALTH ASPECTS OF EMISSIONS FROM IRON AND STEEL MILLS

Knowledge about the health effects of air pollutant emissions from the iron and steel industry is seriously deficient, and studies specifically directed at the problem are almost nonexistent. Lacking such definitive information, we can attempt to pull together bits of several types of more or less pertinent information: (1) Air sampling study areas adjacent to steel mills may give indications of the extent that the industry contributes to the general atmospheric pollution - this aspect was reviewed in a previous section, (2) Observations on the health of community populations in the vicinity of steel mills may indicate whether residence in such areas is proving hazardous,[114-125] (3) Data from the annals of occupational medicine should offer clues to the possible effects of long exposure to high doses of specific agents,[126-159] (4) animal experiments under controlled conditions may give us a firm base line of specific effect from specific cause.[149, 160-163] As promising as this outline may sound, the yield obtainable from it is far less than is desirable.

The evidence from these and other sources presents a complex and uncertain picture concerning operations of the iron and steel industry. Emissions might cause detrimental effects on man's health if present for sufficient periods of time at high enough concentrations. For some emissions, the evidence of potential toxicity is conflicting, one investigator describing adverse effects and another finding none under comparable conditions.

From air sampling studies comes evidence that steel mills do contribute gases and dusts to the atmosphere and that this contribution may significantly increase the levels of some components in the vicinity within a varying geographic radius. The proportions of this contribution depends upon the type of operation, the adequacy of controls, meteorologic and topographic factors, and the quantities of the components contributed to that particular atmosphere by other contaminating sources.

From observations of community effects, we know of acute episodes to which steel operation emissions certainly contributed and are reminded that polluted agricultural crops may contribute a hazard. From Russia, long-term studies suggest that given sufficient time and the proper approach other hazards may be brought to light.

From studies of industrial health we know that many of the dusts—even those usually accepted as "inert" — and at least some of the gases present in steel industry emissions may, in sufficient concentrations over long enough periods of time, produce changes in human tissues. Some of these changes are incapacitating, and may ultimately be fatal in themselves or may provide the nidus for secondary diseases.

Experiments in which animals are exposed to pollutants. provide information useful in considering possible effects of pollutants on man. A vast amount of work of this type has been done. Among the many studies is one in which blast furnace stack dust was found to be inert in rats under the test conditions used.[149]

We do not know the significance of increases in atmospheric pollution levels indicated by some of the air sampling studies, because we have yet to establish permissible community levels for most pollutants. Acute episodes like that in Donora are always possible given the proper set of circumstances, but this does not mean that the steel industry is any more responsible than many others, nor does it mean that the long-term health of the populace is necessarily suffering. Studies—still too embryonic to be meaningful—of comparative mortality rates have not brought forth any convincing evidence that a heavily polluted area like Donora has a seasonal pattern of deaths different from that of the rest of the country, or that human mortality rates are lower during a steel strike than while the mills are operating. Since acute pollution episodes are, or soon should be, completely avoidable, it may be possible to ignore the effects upon subsequent health and survival of those who became ill from exposure to such episodes.[121]

Attempts to apply observations based on occupational diseases to air pollution health effects are apt to distort the point of view in two directions: First, they describe effects produced by exposure 8 hours a day 5 days a week to one or a few agents; and second, these effects have occurred predominantly in a healthy adult working population whose members may be less susceptible to injury than the young, the aged, and the ailing. The Russians have chosen to set many of their industrial threshold limits considerably lower than our own. It may be that they are crying wolf or that we are wearing blinders.

Threshold limits for single agents have been established for industrial exposures, and the manifestations of acute toxicity are well described. For some pollutants, cumulative effects are also known; for others, long-term exposure to industrial concentrations produces pathologic lesions that are usually considered benign; for still others, the chronic effects are controversial.

Existing information on either the toxicity or absence of toxicity of these individual substances cannot be clearly applied to the concentrations or the composite mixtures in which they exist in community situations. With few exceptions, such as the Los Angeles alert levels for some gases and the California ambient air standards, atmospheric threshold limits have not been adopted even for the single agents.

In conclusion, evidence is adequate to show that industry contributes (to a greater or lesser degree, depending on the plant involved) to the total pollution of the surrounding community, and that this contribution includes, in some degree, potentially toxix and hazardous substances such as sulfur dioxide, particulates, and probably certain potentially carcinogenic materials. Further research that will better define the possible effects of air pollutants on man's health must be done before positive cause and effect relationships can be firmly established. Although it cannot be singled out as the contributor of a specific toxicant resulting in any special disease condition, parts of the iron and steel industry and many other pollution sources do add to the steadily increasing burden of known and unknown agents that are potentially a hazard to man's health and welfare. The diminution of these in the community air is desirable, not only by this industry, but by the other contributors as well.

Part VI

AIR POLLUTION LAWS AND REGULATIONS AND THE IRON AND STEEL INDUSTRY

EXISTING LAWS

It is not intended here to present standard or model legislation or to suggest desirable words, phrases, paragraphs or provisions to be incorporated into laws. The purpose of the following discussion is to point out the action that would be required at iron and steel works to bring any uncontrolled emissions into compliance with certain kinds of laws existing today. It is always wise to determine the nature and extent of pollution in the community, the number and kind of pollution sources, and the probable impact of legislation on the community before actually adopting many of the possible provisions of a law. The legislation must be tailored to meet the needs of each particular area.

Regulations of Particulate Matter Emissions (Weight Limitations)

Air pollution control laws and regulations adopted prior to the middle 1920's were designed to bring about control of black smoke emitted from fuel-burning installations. Hand firing of coal was a common practice, and this, and other practices, resulted in emission of excessive amounts of readily visible black carbonaceous particles. As control of this problem moved forward, the public and government officials turned their attention to ash emitted from fuel-burning units, an emission that was increasing because of more general use of mechanical stokers, higher firing rates, pulverized-coal-fired units, and other factors. Thus, laws and regulations adopted after the late 1930's were often designed to bring about control of emission of ash as well as smoke.[164] Ash emission regulations, expressed in various language to limit the weight of material discharged, were generally such that no collectors would be required on domestic stokers or commercial underfeed or traveling-grate stokers operating at reasonably low firing rates. For pulverized-fuel-burning installations and for some types of stokers operating at high firing rates, a stack gas cleaning efficiency of 85 percent or more (by weight) would be required to comply with the limits established. These regulations were based on judgments of the amount of emission that would create a nuisance, efficiency of available control equipment, and the economic impact of the regulations on parties responsible for emissions and, perhaps, their control.

The majority of the laws and regulations designed to bring about control of ash emissions embody a provision that the limitations shall apply only to emissions from combustion equipment. Some do not, however, and the limitations have been applied to all types of sources of particulate matter, including certain operations at iron and steel works, even though, in many situations, the limitations are grossly inadequate to provide for the necessary improvement in air quality and are otherwise inappropriate.

Probably the most commonly used limit prohibits emissions in excess of 0.85 pound of dust per 1000 pounds of carrying gases, adjusted to 50 percent excess air for products of combustion. This value was used in the "Example Sections for a Smoke Regulation Ordinance" published by the American Society of Mechanical Engineers in 1949. This is approximately equivalent to 0.45 grain per cubic foot at 68°F or 0.25 grain per cubic foot at 500°F, limitations that appear in a number of ordinances. Other laws permit emissions as high as 2.5 pounds per 1000 pounds of gases (roughly 1.33 gr/ft ^{3} at 68°F), while other more restrictive laws prohibit emissions in excess of 0.57 pounds per 1000 pounds of gases (roughly 0.30 gr/ft^3 at 68°F). Most of these laws contain a stipulation concerning excess air for products of combustion, in terms of percent excess air *per se* or indirectly in terms of carbon dioxide content of the gases (see "circumvention" later herein).

A more recent development in regulation of emission of particulate matter to the atmosphere has grown from efforts to control air pollution in Los Angeles County, California. Regulations used in other areas in the past were considered inappropriate because of the nature and extent of pollution sources and the adverse meteorological and topographical conditions for dispersion of pollutants in the area. Therefore, during 1948 and 1949, the Los Angeles County Air Pollution Control District set out to develop new standards. Measurements were made of particulate emissions from a variety of operations, including many types of metallurgical processes. Initially, attempts were made to develop emission standards based on visual appearance of the stack effluent or on the total process enthalpy. These were not found entirely satisfactory. Emission limits were finally developed that specified a certain maximum allowable emission in pounds per hour, depending on the total process weight per hour. These limits have been in use since March 1949 in Los Angeles County,[165] and similar limits have been adopted by a number of other jurisdictions. Regulations concerning visual appearance of stack effluents were also adopted (see later herein). In determining allowable emission rates, measured emissions were reduced by factors based on known efficiency of dust- and fume-collecting equipment. The final table of allowable emissions, in terms of pounds per hour, in general, requires a collection efficiency of about 80 percent for small operations and about 90 percent or more for large operations. These collection efficiencies were considered necessary to provide for needed air quality improvement in Los Angeles, were obtainable with available control equipment, and were within the economic reach of the industries that would have to provide control equipment.

Regulations based on process weight apply to operations conducted at iron and steel works, except combustion operations conducted for space and water heating, steam raising, incineration, or salvage purposes. The maximum amount of particulate matter that may be discharged (in pounds per hour) ranges from about 0.5 percent of the process weight (0.5 lb/hr) for plants handling 100 pounds of process materials per hour to 0.067 percent (40 lb/hr) for plants handling 60,000 pounds per hour of process materials. The Los Angeles rule prohibits emission of more than 40 pounds per hour from any one source, whereas the San Francisco Bay Area regulation permits emission of more than 40 pounds per hour from very large plants but allows only a very small percent of the process weight to be emitted, e.g., 0.0069 percent of the process weight for a 1,000,000-pound-per-hour operation. Some other jurisdictions using this type regulation permit a higher percent of the process weight to be emitted in the case of large operations. Riverside County, California, has a rule of this type. The Bay Area regulation has a further stipulation concerning the minimum concentration of particulate matter that can be required, in terms of grains per scf in exit gases. Values range from 0.1 grain per scf for an emission of 7000 scfm to 0.02 grain per scf for an emission of 1,000,000 scfm or more.

The Allegheny County, Pennsylvania, Health Department on July 5, 1960, enacted regulations dealing specifically with weight of particulate matter discharged from iron and steel mill operations. Emissions from blast furnaces, after burning, are limited to not more than 0.35 pound per 1000 pounds of gases. Particulate matter in excess blast furnace gas being bled to the atmosphere is limited to 0.50 pound per 1000 pounds of gases. The limitations do not apply during "slips" of the furnace burden. A device for recording occurrence of "slips" is required. Persons responsible for operation of blast furnaces must conduct research to determine methods of controlling emission of pollutants during "slips." Emissions from open hearth and electric furnaces and sintering plants built after July 5, 1960, are not to exceed 0.2 pound per 1000 pounds of exhaust gases. A program that will require continued installation of air pollution control devices (or replacement of facilities) to reduce emissions from existing installations to this level is to be recommended by an advisory committee for approval of the Board of Health; a reasonable period of time for compliance will be allowed. Persons responsible for these units are also required to do research on methods of further controlling emissions. Basic oxygen steel furnaces are limited to an emission of 0. 2 pound or less per 1000 pounds of exhaust gases. Particulate emissions from heating and reheating furnaces are limited to not more than 0. 30 pound per 1000 pounds of gases, and emissions from air furnaces are not permitted to exceed 0. 50 pound per 1000 pounds of gases.

Steubenville, Ohio, has an ordinance similar to that of Allegheny County but has slightly more lenient limitations on a few processes. Lorain, Ohio, prohibits emissions of more than 1. 0 pound per 1000 pounds of exit gas from blast furnaces, heating and reheating, and air furnaces. That city further provides that coke plants, open hearth furnaces, sintering plants, and Bessemer converters "shall incorporate those means of controlling particulate matter emission which have been proven economically practical."

Enactment of laws or regulations providing for control of emissions of particulate matter based on technical standards (such as lb/hr or lb/1000 lb of exhaust gases) impose a responsibility to measure emissions. This is a formidable job, requiring trained personnel, laboratory and field equipment, process information, etc. The control agency must be provided with resources to do this work, or as an alternative, the law may require persons responsible for emissions to conduct necessary tests. Even then the control agency must have personnel who can insure that tests are properly conducted.

Regulation of Visible Emissions

Nearly all air pollution control ordinances or regulations embody a limitation on visible emissions, particularly dense smoke. The Ringelmann Chart is used almost universally as the standard for determining smoke density, although some laws permit use of other equivalent means. These regulations were designed primarily for use in controlling black smoke from fuel-burning devices used for space and water heating, steam raising, and refuse incineration. In some areas, however, the same regulation used to control smoke from fuel-burning operations is used in an effort to control emissions from iron and steel works, even though, in many cases, such regulations are grossly inadequate to provide for the necessary improvement in air quality.

The most common fuel-burning regulation prohibits smoke, the shade or appearance of which is equal to or darker than No. 2 of the Ringelmann Chart. Some darker smoke is usually permitted for a few minutes (usually 4) in any half-hour and for a few minutes (usually 3) in a 15-minute period, when a fire is being cleaned or built. A wide variety of limitations, more and less severe, exists.

A few communities have adapted use of the Ringelmann Chart to a procedure for measuring visible emissions other than black smoke. Emissions having an opacity that obscures an observer's view to a degree equal to or greater than smoke of a stated Ringelmann number are prohibited. This "equivalent opacity" regulation would be applicable to certain iron and steel mill emissions, particularly open hearth, electric, and basic oxygen steel furnaces. For these sources, the equivalent opacity limitation may be more difficult to comply with than a relatively severe limitation on weight of particulate emissions. This situation is due to the great light-scattering power of the very fine particles emitted from these furnaces. They would not constitute a great amount of weight and are more difficult to collect than large particles. As little as 0.05 grain per scf in an exhaust stack may cause a visible plume.

The Allegheny County, Pennsylvania, Health Department regulations include special provisions for dense smoke from byproduct coke ovens. A generally applicable clause prohibits smoke darker than Ringelmann No. 2. This applies to coke plants and includes smoke leaking out of oven doors. However, more dense smoke is permitted for 12 minutes in any 60-minute period when coke is charged to a battery of ovens and when coke is pushed from a battery of ovens. Emission of smoke from heating, reheating, and air furnaces may not be darker than Ringelmann No. 2, but during an aggregate of 6 minutes in any 60-minute period, darker smoke is permitted. Blast furnaces, open hearth and electric furnaces, sintering machines, basic oxygen furnaces, and Bessemer converters are exempted from the dense smoke limitation.

Miscellaneous Regulations

The great majority of air pollution laws and regulations contain a clause relative to nuisances caused by air pollutants. Furthermore, nearly all jurisdictions have a general nuisance law applicable to unsatisfactory conditions caused by air pollutants. Such regulations typically prohibit emission of pollutants in a manner or in amounts that cause injury, detriment, nuisance, or annoyance to the public, that endanger the public comfort, welfare, health, or safety, or that cause injury to business or property. These anti-nuisance laws can be used as a basis for requiring control of air pollution problems caused by iron and steel works, problems such as odors, excessive dustfall, and soiling of property. The legal and administrative procedures are cumbersome, however, and it is often difficult to demonstrate conclusively that a certain problem or specific portion of a problem is caused by a given pollution source. This is especially true in large urban areas.

Allegheny County, in addition to other regulations described above, has prohibited operation of beehive coke ovens. Also, construction of new Bessemer converters is not permitted until equipment has been developed that will prevent emissions in excess of 0.65 pound of dust per 1000 pounds of gases at 50 percent excess air for products of combustion.

Most of the limitations on weight of emission of particulate matter do not have special provisions concerning size of particles emitted. A few regulations (usually those designed primarily for control of emissions from coal-fired boilers) limit the part of the total particulate emission that may consist of particles greater than 44 microns in diameter or that are retained on a U. S. Standard 325-mesh screen. The most common regulation of this type prohibits emission of more than 0.2 pound of particulate matter, larger than 44 microns, per 1000 pounds of gases. Some steel mill operations might be affected by such regulations.

Regulations applicable to emission of gaseous air pollutants have been adopted by only a few jurisdictions and with respect to only a few pollutants. The usual anti-nuisance laws can, however, be used to regulate gaseous emissions that create odor problems; cause some sort of demonstrable injury, detriment, or annoyance to man; or cause injury to vegetation, animals, or property. Sulfur dioxide and fluorine compounds (the latter may be in gaseous or particulate form) are pollutants that arise at steel mills and have been subject to specific regulations. A few jurisdictions (perhaps six) limit sulfur dioxide concentration in exhaust gases to 0.2 percent. One regulation (San Francisco Bay Area) further limits emission on the basis of concentration of sulfur dioxide caused at locations off the plant premises, at ground level. This, in effect, limits rate of emission. One regulation (San Bernardino County, Calif.) prohibits emission of "that amount of fluorine compounds which causes injury to the property of others."

Since many regulations embody limitations on emission of particulate matter in terms of grains per cubic foot or pounds of dust per 1000 pounds of carrying gases, it becomes necessary to arrive at some reasonable volume of gases, going through the equipment and being discharged, that is needed to carry on the operation properly. Otherwise, before discharged, the effluent could be diluted with air to the extent necessary to meet the emission limitation without actually reducing the total weight of particulate matter emitted. Since pollution levels in the ambient air are a function of the amount of pollutant discharged per unit time, such dilution would have nearly no beneficial effect on ambient air quality. In the case of emission of particulate material from combustion operations, the matter is handled by providing that stack concentration of particulate matter be adjusted to the basis of 50 percent excess air for products of combustion; however, this procedure is not applicable to many iron- and steel-making processes. A few regulations contain a specific clause to control actions that would make it possible for an operation to comply with regulations and yet not actually reduce emission of pollutants. The Los Angeles County regulation on this matter (circumvention) states that "a person shall not build, erect, install, or use any article, machine, equipment, or other contrivance, the use of which, without resulting in a reduction in the total release of air contaminants to the atmosphere, reduces or conceals an emission which would otherwise constitute a violation..." Regulations that limit emissions in terms of pounds per hour are much less subject to problems associated with determination of a reasonable gas volume discharge since, in such regulations, it makes no difference whether the pollutants are more concentrated in a small volume of gases or more diluted in a large volume.

The Chicago ordinance of May 1, 1959, exempts from air pollution regulations all blast furnaces and auxiliaries, byproduct coke plants, open hearth furnaces, sintering plants, Bessemer converters, pneumatic steel-making furnaces, electric furnaces, and a few other installations. The ordinance provides that research shall be conducted to determine feasible methods for controlling smoke and particulate matter from this equipment. Until such time as definitive standards are established for these installations, emissions of smoke and particulate matter are not to exceed those associated with "normal good operating practice."

Some ordinances and regulations stipulate the maximum efficiency to be required of dust-collecting equipment. Commonly used maximum required efficiencies are 85 percent for installations built subsequent to adoption of the regulation and 75 percent for installations built prior to the effective date of the regulation. These provisions were designed primarily for fuel-burning equipment and represent an economic compromise based on collection equipment and equipment costs existing 10 to 15 years ago. These values are based on consideration of ash content of coal, effect of boiler load changes on collector efficiency, space available to install collectors, expected life of plants, etc.

A few regulations contain specific provisions concerning control of wind-borne dust from handling or storing materials or from dusty roadways or parking lots, building or wrecking operations, etc. The Allegheny County regulations require that reasonable precautions be taken to minimize air pollution in such situations.

RELATIONSHIP OF SOME REGULATIONS TO EFFICIENCIES OF CONTROL EQUIPMENT

In this section, consideration is given to the types of control equipment needed to meet various emission limitations. The discussion must be considered only in generalities because of the wide variation that exists between equipment, raw materials, fuels, and operating procedures. An evaluation is necessary for each situation in actual practice.

Equipment necessary to bring iron- and steel-making processes into compliance with regulations will be discussed in terms of the following: (1) Los Angeles County process-weight regulations, (2) San Francisco Bay Area regulations based on process weight and minimum grain loadings to be required, (3) Allegheny County regulations, (4) visible emission limitations, and (5) other regulations such as those concerning odors, sulfur dioxide, and fluorides.

Sintering Machines

Use of well-designed inertial separators (cyclones and devices of similar efficiency) might make it possible to comply with Allegheny County regualtions. In other cases and in order to meet Los Angeles and San Francisco regulations, high-efficiency collectors (electrostatic precipitators, high-efficiency scrubbers, and bag houses) possibly in series with an inertial separator will be required. Visible emissions probably will not present problems nor will odors or sulfur dioxide. Fluoride emissions may cause neighborhood problems when certain western United States ores are used. Equipment for control of fluorides in such cases is described in detail elsewhere herein.

Coke Plants

Data reviewed were not adequate to determine whether emission of particulate matter from coke plants would be in violation of the various regulations concerned with weight of particulate matter emitted. Control of emissions to the extent necessary to comply with visible emission regulations of Allegheny County would require application of operating and oven-door maintenance practices described elsewhere herein. Emission of materials causing odors in the surrounding community would also be reduced by such control practices. Emission of sulfur dioxide would not be expected to exceed amounts allowed by regulations except, perhaps, in the event that a sulfuric acid plant were part of the byproduct processing plant. Emission of fluorides would not be of major concern.

Blast Furnaces

Blast furnace gases, after passing through a preliminary cleaner such as a settling chamber or cyclone and a primary cleaner such as a wet scrubber, would in many cases contain particulate matter in excess of that allowed by Allegheny County regulations and in nearly all cases would exceed those allowed by Los Angeles and San Francisco regulations. Compliance with these regulations would require secondary collectors (in series with primary collectors) with efficiencies of around 90, 80, and 70 percent, respectively, in Los Angeles, San Francisco, and Allegheny County. Since most of the larger particles are removed by the first two stages of the gas-cleaning system, the secondary collector would have to be effective in collecting fine particles to achieve the required efficiency. Such devices would be electrostatic precipitators, high-energy scrubbers, or perhaps fabric filters. No particular measures would be necessary to comply with regulations concerned with visible or other pollutant emissions; however, the gases should be burned either in heat-exchange equipment or in waste-gas burners to prevent release of large volumes of carbon monoxide.

Open Hearth Furnaces

For an average-size furnace (175-ton capacity) a collector with an efficiency of 70 to 75 percent would be required to meet emission-weight regulations of Allegheny County, San Francisco, and Los Angeles on a furnace not using roof lances. An efficiency of around 80 percent would be required if oxygen were used. Collectors that can provide this efficiency include electrostatic precipitators, high-energy scrubbers, and fabric filters. Higher efficiencies would be required for larger furnaces in order to comply with regulations of Los Angeles and San Francisco. Emission control necessary to meet equivalent opacity regulations requires high-efficiency collectors. Exit-gas loadings would have to be about 0.05 grain per scf (and perhaps lower) to eliminate the visible plume from an open hearth. This would indicate that collectors on furnaces using oxygen would have to remove about 95 percent of the particulate matter. The corresponding figure for regular open hearths is about 92 percent. Such efficiencies require excellent collection equipment. Sulfur dioxide emissions from open hearths will generally meet regulations without special control measures, since process considerations require low sulfur input to the furnace. Emission of fluorides may cause a neighborhood situation in violation of regulations at the few plants where ores containing unusually large amounts of fluorine are used. The causes, nature, and means for control of this problem are described elsewhere herein.

Electric Furnaces

Although the appearance of emissions from electric furnaces gives the impression that a tremendous amount of pollution is being emitted, the actual weight of material discharged is not particularly large, since the small particle size of the material emitted enhances its light-scattering properties, forming a dense visible plume. To comply with emission-weight regulations of San Francisco and Los Angeles, collection efficiencies of more than 80 percent would be required. Compliance with Allegheny County regulations would require a slightly less efficient collector. Compliance with equivalent opacity regulations is difficult for electric furnaces. Exit-gas grain loadings to meet such regulations would probably be lower than loadings permitted by emission-weight restrictions. Collector efficiencies needed to meet visible emission limitations may be greater than 85 percent. Such efficiencies can be achieved only with collectors highly effective in collecting small particles, collectors such as electrostatic precipitators, high-energy scrubbers, and fabric filters. Emissions of odorous materials, sulfur dioxide, and fluorides are of little concern with respect to air pollution from electric furnaces and no problem in complying with regulations would be expected.

Bessemer Converters

Emissions from Bessemer converters exceed virtually all limitations on weight of particulate matter emitted and on visible emissions. No feasible means are available for bringing these furnaces into compliance with limitations applicable to other pollution sources. In Allegheny County, existing furnaces are exempted from compliance with regulations and construction of new furnaces is prohibited until suitable controls are available and used. In other areas, violations are allowed to continue by issuance of a variance to the regulations, by ordinance provisions exempting these furnaces from application of emission limitations, or by simply not enforcing regulations.

Basic Oxygen Furnaces

Basic oxygen furnaces produce a large amount of fine particulate matter. Emissions far exceed all regulations on weight of emissions. To comply with emission-weight regulations of Los Angeles County, the San Francisco Bay Area, and Allegheny County, efficiencies of 98 percent or better would be required. Equivalent opacity regulations will be of particular concern, and to produce an effluent in compliance with strict regulations of this type will require excellent control equipment. In all cases, only the most efficient type of collector, properly designed and operated, can provide the necessary high performance. Sulfur dioxide, fluoride, and odorous material emissions are unlikely to violate air pollution regulations.

Heating and Reheating Furnaces

Inadequate firing or combustion-control equipment or improper operation may lead to smoke emissions from heating and reheating furnaces in excess of those allowed by regulations. The use of instruments and automatic combustion controls and modern combustion equipment will prevent most excessive smoke emissions. Allegheny County regulations provide a special modest exception to general smoke emission limits so that some smoke darker than No. 2 Ringelmann Chart may be legally emitted. Most of these furnaces use liquid or gaseous fuels that would not be expected to cause emission of particulate matter in excess of that permitted by regulations dealing wtih the weight of the particulate matter emitted. If a fuel containing a high percentage of sulfur is burned, there might be a violation of sulfur dioxide emission limits. Control, if needed, would probably be accomplished by changing to a fuel of lower sulfur content. Emission of fluorides or odorous materials would not be expected to exceed that allowed by regulations.

Scarfing Machines

Data concerning emissions from scarfing machines are adequate only for tentative indications of control equipment that might be required to comply with air pollution regulations. That control equipment is necessary is indicated by exit-gas grain loadings in the range of 0. 2 to more than 0. 8 grain per scf and daily effluent rates ranging from 1000 to more than 7000 pounds, according to various reports. Collection efficiencies required to meet equivalent opacity regulations would probably be around 90 percent. Efficiencies of around 75 percent would probably provide sufficient control to comply with the majority of the emission-weight regulations. Emission of sulfur dioxide and fluorides would not be expected to exceed legal limits.

Power Plant Boilers

Power plant boilers are subject to emission-weight regulations applicable to fuel-burning installations. Powdered-coal-burning plants would usually have to use collectors of about 90 percent efficiency to meet these standards. Electrostatic precipitators, perhaps in series with high-efficiency inertial collectors, are commonly used to control emissions from powdered-coal-burning plants. Spreader stokers would need control equipment with efficiencies in the 75 to 90 percent range, depending on fuel-burning rate and other factors, in order to meet emission-weight limitations. In many cases, high-efficiency inertial separators would be adequate, but in others, electrostatic precipitators may be necessary. Most other types of furnaces using coal would not need collectors to comply with regulations unless extremely high firing rates were used. Oil- and gas-fired furnaces do not emit particulate matter at a rate in excess of emission-weight limits.

Power plant boilers are also subject to regulations concerned with visible smoke emissions. Excessive smoke may often be prevented by giving suitable attention to fuel specifications, furnace maintenance, and firing practices. Installation of overfire-air, steam, or steam-air jets would assist in preventing smoke in some cases. Smoke from over-loaded plants can be eliminated by reducing the load on the plant. Coal- and oil-fired plants may emit excessive smoke, but gas-fired plants rarely have this problem. Emissions from certain oil-fired plants sometimes exceed equivalent opacity regulations even though no black smoke is ememitted. The visible plume is due at least in part to sulfur trioxide and can be controlled by use of electrostatic precipitators and, if available, low-surfur-content oil.

Plants using coal or oil with a high sulfur content may emit sulfur dioxide in excess of legal limits. No economically attractive means of controlling this emission is available. Obviously, use of lower-sulfur-content fuel would eliminate the problem. Emission of fluorides and odorous materials is not expected to exceed legal limits.

REFERENCES

1. American Iron and Steel Institute. Directory of Iron and Steel Works of the United States and Canada. 29th ed. American Iron and Steel Institute, New York, N. Y., 1960. 519 pp.

2. Camp, J. M. and Francis, C. B. The Making, Shaping, and Treating of Steel. 6th ed. United States Steel Co., Pittsburgh, Pa., 1951. 1584 pp.

3. Hemeon, W. C. L., ed. Air pollution problems of the steel industry. Technical Coordinating Committee T-6, steel report, Section I. JAPCA. 7:62-67. May 1957.

4. American Iron and Steel Institute. The Making of Steel. American Iron and Steel Institute, New York, N. Y., 1954. 95 pp.

5. Hemeon, W. C. L., ed. Air pollution problems of the steel industry. Technical Coordinating Committee TI-6, Sections II through VII. JAPCA. 10:208-18, 253. June 1960.

6. Colclough, T. P. Sulfur in iron and steelmaking. In: Problems and Control of Air Pollution, F. S. Mallette, ed. Reinhold Publishing Corp., New York, N. Y., 1955. pp. 202-14.

7. Purvance, W. T. Atmospheric pollution control. Chem. Eng. Progr. 55:49-53. July 1959.

8. Linde roof jet information. Linde Company, Development Laboratory, Newark, N. J. 11 pp.

9. Hodge, A. L. and Arnold, C. S. How oxygen input affects open-hearth steelmaking. J. Metals. 12:325-30. 1960.

10. Ford reveals new technique in OH steelmaking with oxygen. Iron Steel Engr. 37:145. June 1960.

11. Brief, R. S., Rose, A. H., and Stephan, D. G. Properties and control of electric-arc steel furnace fumes. JAPCA. 6:220-24. Feb. 1957.

12. Fedock, M. P. Melting practice and refractories performance in basic electric-arc furnaces. Ind. Heating. 20:135-36, 138, 140. Jan. 1953.

13. Hind, G. W. and Hodge, A. L. The use of oxygen-fuel gas burners for scrap meltdown in electric furnaces. Presented at the Electric Furnace Conference, Cleveland, Ohio. Linde Company, Development Laboratory, Newark, N. J.

14. Yocum, G. and Xidis, L. Blowing methods in steelmaking. Iron Steel Engr. 37:101-07. Sept. 1960.

15. Vajda, S. Symposium on basic oxygen furnaces. Equipment layout. Iron Steel Engr. 37:73-78. Oct. 1960.

16. Smith, D. W. Symposium on basic oxygen furnaces. Operations. Iron Steel Engr. 37:85-89. Oct. 1960.

17. The promise of the sixties. AISE Forum. Steel. 147:154, 157, 160, 162, 166, 168. Sept. 19, 1960.

18. Jaklitsch, J. J., Jr., ed. Briefing the record - Sintering. Mech. Eng. 79:35-36. Jan. 1957.

19. New 5000 tons per day sintering plant at U. S. Steel's Ohio works. Ind. Heating. 26:86-94. Jan. 1959.

20. Morgan, M. F. and Collison, W. H. Symposium on sinter plants-discussion. Iron Steel Engr. 36:101-22. June 1959.

21. McMahan, J. S. The use of self-fluxing sinter. Blast Furnace Steel Plant. 47:51-54. Jan. 1959.

22. DeCarlo, J. A. and Otero, M. M. Coke plants in the United States on December 31, 1958. Information Circular 7934, U. S. Bureau Mines, 1959. 20 pp.

23. Metal Market Bureau. Beehive coke oven use up; revival won't last. Reprinted in Smog News (ASME). No. 160:19. May 15, 1960.

24. DeCarlo, J. A. and Ryan, E. E. Beehive-coke plants in the United States that reported to Bureau of Mines in 1956. Information Circular 7820, U. S. Bureau Mines, Jan. 1958. 17 pp.

25. Raleigh, W. A., Jr. Outlook - steel and coal. Coal Age. 65:76-79. Sept. 1960.

GPO 804-624-8

26. U. S. Bureau of the Census. Statistical Abstract of the United States, 1958. 79th ed. U. S. Dept. Commerce, Washington, D. C., 1958. 1040 pp.

27. Industry - new era for steel. Time, April 7, 1961. pp. 90, 92, 94.

28. Parker, C. M. American Iron and Steel Institute. Personal communication with J. J. Schueneman, U. S. Public Health Service. Feb. 1960.

29. Davis, D. O. The oxygen steelmaking process. Blast Furnace Steel Plant. 44:44-48, 108. Jan. 1956.

30. Jaklitsch, J. J., Jr. loc. cit.

31. O'Mara, R. F. Dust and fume problems in the steel industry. Air Pollution Symposium. Iron Steel Engr. 30:100-06. Oct. 1953.

32. Meadley, A. H., Colvin, J. G., and Camble, H. J. Mitigation of air pollution in sinter plants. In: Air and Water Pollution in the Iron and Steel Industry, Special Report No. 61. Iron and Steel Institute, London, England, 1958. pp. 39-48.

33. Granville, R. A. The capital costs of some waste-gas cleaning plants for use in iron and steel works. In: Air and Water Pollution in the Iron and Steel Industry, Special Report No. 61. Iron and Steel Institute, London, England, 1958. pp. 23-30.

34. Brooks, S. H. and Calvert, W. J. External pollution from an iron and steel works and measures towards its reduction. In: Air and Water Pollution in the Iron and Steel Industry, Special Report No. 61. Iron and Steel Institute, London, England, 1958. pp. 5-15.

35. Corzilius, W. R. Sintering plant expands blast furnace and open hearth capacity. Blast Furnace Steel Plant. 47:44-50. Jan. 1959.

36. Semrau, K. T. Emission of fluorides from industrial processes - a review. JAPCA. 7:92-108. Aug. 1957.

37. Gallear, C. A. Reduced turbulence boosts dust collector efficiency. Iron Age. 176:98-100. Sept. 1, 1955.

38. Brandt, A. D. Air pollution control in the Bethlehem Steel Company. Air Repair. 3:167-69. Feb. 1954.

39. Specht, S. E. and Sickles, R. W. New uses of electrical precipitation for control of atmospheric pollution. Air Repair. 4:137-40, 170. Nov. 1954.

40. Thring, M. W. and Sarjant, R. J. Dust problems of the iron and steel industry. Iron and Coal Trades Rev. 174: 731-34. Mar. 29, 1957.

41. Kurtz, J. K. Recovery and utilization of sulfur from coke oven gas. In: Problems and Control of Air Pollution, F. S. Mallette, ed. Reinhold Publishing Corp., New York, N. Y., 1955. pp. 215-21.

42. Beryushev, K. G. Limits of allowable concentration of phenol in the atmospheric air of inhabited localities. In: Limits of Allowable Concentrations of Atmospheric Pollutants. Book 2-1955. V. A. Ryazanov, editor, and B. S. Levine, translator. (Publication No. 59-21174). U. S. Dept. of Commerce, Office of Technical Services, Washington, D. C. pp. 65-68.

43. Radcliffe, J. C. and Delhey, W. F. An industrial air pollution program. In: Proc. 45th Annual Meeting, Air Pollution and Smoke Prevention Assoc. of America, Cleveland, Ohio, June 9-12, 1952. pp. 40-45.

44. Kemp, W. E. Product fallout - a serious corrosion problem. Ind. Eng. Chem. 51:75A-76A. July 1959.

45. Mallette, F. S. A new frontier: air pollution control. (James Clayton Paper). Inst. Mech. Engrs. (London), Proc. 168(No. 22):595-628. Apr. 1954.

46. Bishop, C. A. Metallurgical furnace stacks. AIHA Quart. 11:34-39. Mar. 1950.

47. Howell, G. A. Air pollution control in the steel industry. Air Repair. 3:163-66. Feb. 1954.

48. Hosey, A. D. and Nevins, F. Evaluation of plant effluents. In: Air Pollution in Donora, Pa. - Preliminary Report. Public Health Bull. No. 306, 1949. pp. 86-109.

49. Basse, B. Gases cleaned by use of scrubbers. Blast Furnace Steel Plant. 44:1307-10. Nov. 1956.

50. Wurts, T. C. Industrial sources of air pollution - metallurgical. In: Proc. National Conference on Air Pollution, Washington, D. C., Nov. 18-20, 1958. PHS Publ. 654, 1959. pp. 161-64.

51. Bishop, C. A. et al. Cleaning ferromanganese blast furnace gas. Iron Steel Engr. 28:134-36. Aug. 1951.

52. Allen, G. L., Viets, F. H., and McCabe, L. C. Control of metallurgical and mineral dusts and fumes in Los Angeles County, Calif. Information Circular 7627, U. S. Bureau Mines, Apr. 1952. 79 pp.

53. Billings, C. E., Small, W. D., and Silverman, L. Pilot-plant studies of a continuous slag-wool filter for an open-hearth fume. JAPCA. 5:159-66. Nov. 1955.

54. Open hearth furnace fumes - their formation and resulting problems. Iron and Coal Trades Rev. 173:1311-17. Nov. 30, 1956.

55. Bishop, C. A. Some experiences with air pollution abatement in the steel industry. In: Proc. 45th Annual Meeting, Air Pollution and Smoke Prevention Assoc. of America, Cleveland, Ohio, June 9-12, 1952. pp. 32-37.

56. Pring, R. T. Filtration of hot gases. Air Repair. 4:40-45. May 1954.

57. Bishop, C. A., Campbell, W. W., Hunter, D. L., and Lightner, M. W. Successful cleaning of open-hearth exhaust gas with a high-energy venturi scrubber. JAPCA. 11:83-87. Feb. 1961.

58. Smith, J. H., Rounds, G. L., and Matoi, H. J. Some problems encountered in sampling open hearth stacks. Air Repair. 3:35-40. Aug. 1953.

59. Akerlow, E. V. Modification to the Fontana open hearth precipitators. JAPCA. 7:39-43. May 1957.

60. Strauss, W. Cleaning waste gases from open-hearth steel processes. Chem. and Proc. Eng. 41:339-43, 351. Aug. 1960.

61. Speer, E. B. Operation of electrostatic precipitators on O.H. furnaces at Fairless Works. In: Air and Water Pollution in the Iron and Steel Industry, Special Report No. 61. Iron and Steel Institute, London, England, 1958. pp. 67-74.

62. Silverman, L. Cleaning of open-hearth stack gases. Blast Furnace Steel Plant. 43:735-38. July 1955.

63. Great Britain. Ministry of Housing and Local Government. 85th Annual Report on Alkali etc. Works by the Chief Inspectors, 1948. H. M. Stationery Office, London, England, 1949. 43 pp.

64. Ibid. 86th Annual Report, 1949. 41 pp.

65. Holden, C. Factors affecting fuming in open hearth furnaces. J. Iron Steel Inst. (London). 193:93-102. Oct. 1959.

66. Knaggs, K. and Slater, J. M. Some factors affecting fume evolution from molten steel during oxygen injection. J. Iron Steel Inst. (London). 193:211-16. Nov. 1959.

67. Silverman, L. Technical aspects of high temperature gas cleaning for steel making processes. Air Repair. 4:189-96, 231. Feb. 1955.

68. Lindstrom, C. A. U. S. Public Health Service, Division of Air Pollution. Personal communication with M. D. High, U. S. Public Health Service, Feb. 1961.

69. Vajda, S. and Dreher, G. M. Open hearth dust control. In: Proc. 45th Annual Meeting, Air Pollution and Smoke Prevention Assoc. of America, Cleveland, Ohio, June 9-12, 1952. pp. 26-32.

70. Richardson, H. L. Scope of the furnace fume control problem. Iron Steel Engr. 33:105-11. Jan. 1956.

71. Turner, N. H. Use of oxygen in modified tilting furnace - dust removal plant. J. Iron Steel Inst. (London). 190:20-22. Sept. 1958.

72. Dracco receives order. JAPCA. 10:474. Dec. 1960.

73. Steel Companies and Air Pollution Control Equipment Manufacturers. Personal communications with J. J. Schueneman. Feb. and Mar. 1961.

74. Coulter, R. S. Bethlehem Pacific Coast Steel Corporation. Personal communication. Apr. 24, 1956.

75. Coulter, R. S. Smoke, dust, fumes closely controlled in electric furnaces. Iron Age. 173:107-10. Jan. 14, 1954.

76. Los Angeles County Air Pollution Control District. Unpublished data. Los Angeles, California. 1950-1951.

77. Kane, J. M. and Sloan, R. V. Fume control-electric melting furnaces. Am. Foundryman. 18:33-35. Nov. 1950.

78. Pier, H. M. and Baumgardner, H. S. Research-Cottrell, Inc. Personal communication. Apr. 17, 1956.

79. Faist, C. A. Remarks. Electric Furnace Steel, Proc. (Am. Inst. Mining Met. Engrs.). 11:160-61. 1953.

80. Faist, C. A. Burnside Steel Foundry Co. Personal communication. Apr. 25, 1956.

81. Anderson, E. F. There are indirect benefits from the furnace fume collector. Foundry. 83:152-53. Sept. 1955.

82. Everling, W. O. Extent to which available control technique have been utilized by industry - iron and steel. In: Proc. National Conference on Air Pollution, Washington, D. C., Nov. 18-20, 1958. PHS Publ. 654. 1959. pp. 339-43.

83. Los Angeles Air Pollution Control District. Emissions of oxides of nitrogen from stationary sources in Los Angeles County. Report No. 2, Oxides of nitrogen emitted by small sources. A Joint District, Federal, State, and Industry Project. Los Angeles County Air Pollution Control District, Los Angeles, California, Sept. 1960. 73 pp.

84. Lewis, W. E. Remarks. Electric Furnace Steel, Proc. (Am. Inst. Mining Met. Engrs.). 10: Dec. 1952.

85. Erickson, E. O. Dust control of electric foundries in Los Angeles area. Electric Furnace Steel, Proc. (Am. Inst. Mining Met. Engrs.). 11:156-60. 1953.

86. Assel, W. J. Remarks. Electric Furnace Steel, Proc. (Am. Inst. Mining Met. Engrs.). 10:47. Dec. 1952.

87. Kane, J. M. The application of local exhaust ventilation to electric melting furnaces. Trans. Am. Foundrymen's Soc. 52:1351-56. 1944.

88. Dok, H. Smog control in the steel industry. JAPCA. 5:23-26. May 1955.

89. Dok, H. Smog control in the foundry. Am. Foundryman. 26:46-49. Dec. 1954.

90. Bloomfield, B. D. An appraisal of air pollution control installations. AIHA Quart. 17:434-44. Dec. 1956.

91. American Foundrymen's Society. Control of emissions from metal melting operations. American Foundrymen's Society, Des Plaines, Ill., 1955. 26 pp.

92. Anderson, E. F. Wheelabrater Corp. Personal communication. Apr. 30, 1956.

93. Sarjant, R. J. Steelmaking processes in relation to atmospheric pollution. Iron and Steel (London). 32:185-90. May 1959.

94. Dehne, W. Possibilities of removing dust from brown converter waste gas Iron and Coal Trades Rev. 175:477-82. Aug. 30, 1957.

95. Parker, C. M. American Iron and Steel Institute. Personal communication with V. G. MacKenzie, U. S. Public Health Service. Apr. 11, 1961.

96. Gaw, R. G. Symposium on basic oxygen furnaces. Gas cleaning. Iron Steel Engr. 37:81-85. Oct. 1960.

97. Vacek, A. and Schertler, A. Waste-gas cleaning systems at oxygen steel plants. In: Air and Water Pollution in the Iron and Steel Industry, Special Report No. 61. Iron and Steel Institute, London, England, 1958. pp. 82-89.

98. Dust control: dust settling chambers keep Canton's air clean. Iron Age. 175:119-20. June 23, 1955.

99. Hemeon, W. C. L., Haines, G. F., and Ide, H. M. Determination of haze and smoke concentrations by filter paper samplers. Air Repair. 3:22-28. Aug. 1953.

100. Munroe, W. A. Statewide air pollution survey - smoke index. Public Health News, New Jersey State Department of Health, Trenton, N. J. 39:227-42. Aug. 1958.

101. Tabor, E. C. and Meeker, J. E. Effects of the 1956 steel strike on air pollution levels in several communities. In: Proc. 51st Annual Meeting APCA, Philadelphia, Pa., May 25-29, 1958. 58-24. 20 pp.

102. Dyktor, H. G. and Goldston, L. N. The effects of the steel industry on atmospheric pollution in the Cleveland area. Industrial Hygiene Newsletter. 11:22-23. Feb. 1951.

103. Consumers Union of U. S., Inc. Pollution in the air we breathe. Consumer Reports. 25:400-07. Aug. 1960.

104. Paulus, H. J., Hosey, A. D., Crothers, R. B., and Byers, D. H. Investigation of atmospheric contaminants. In: Air Pollution in Donora, Pa. - Preliminary Report. Public Health Bull. No. 306, 1949. pp. 81-125.

105. International Joint Commission. Technical Advisory Board on Air Pollution, United States Section. Report of results of sampling the atmosphere in the Detroit River area during 1951. Mar. 1, 1953. 55 pp.

106. International Joint Commission. Technical Advisory Board on Air Pollution, United States Section. Report on 1953 environmental studies in the Detroit River area. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, Apr. 1, 1955. 56 pp.

107. Jones, H. G. and Davies, J. T. External dust deposition and sulfur emission. In: Air and Water Pollution in the Iron and Steel Industry, Special Report No. 61. Iron and Steel Institute, London, England, 1958. pp. 16-23.

108. Kirste, H. Dust measurements to determine the sources of emissions damaging crops. In: Proc. International Clean Air Conference, London, Oct. 20-23, 1959. National Society for Clean Air, London, England, 1960. pp. 154-56.

109. Leclerc, E. On the determination of the degree of atmospheric pollution of city atmosphere. Rev. Universelle Mines (Belgium). 9(Ser. 9):801-08. Dec. 1953.

110. Cholak, J., Schafer, L. J., and Yeager, D. Air pollution near an iron slag processing plant. AIHA Quart. 15:220-25. Sept. 1954.

111. Dickun, P. P. and Nikberg, I. I. A study of air pollution with 3,4-benzpyrene in the vicinity of an old pitch-coke plant. In: U.S.S.R. Literature on Air Pollution and Related Occupational Diseases - Vol. 2. A survey and translation by B. S. Levine. (Publication No. 60-21188). U. S. Dept. of Commerce, Office of Technical Services, Washington 25, D. C., Mar. 1960. pp. 135-40.

112. Sawicki, E. et al. Benzo(a)pyrene content of the air of American communities. AIHA J. 21:443-51. Dec. 1960.

113. U. S. Weather Bureau. Meteorology and Atomic Energy. AECU-3066. U. S. Government Printing Office, Washington, D. C., July 1955. 169 pp.

114. Firket, J. et al. The causes of the symptoms found in the Meuse Valley during the fogs of December 1930. Bull. acad. roy. med. Belg. 11:683-741. 1931. (Abstract 18 in reference 115)

115. Cincinnati. University. Kettering Laboratory of Applied Physiology. Annotated Bibliography. The Effects of Atmospheric Pollution on the Health of Man. University of Cincinnati, Cincinnati, Ohio, 1957. 481 pp.

116. Heimann, H., David, W. D., and Sitgreaves, R. The acute illness. In: Air Pollution in Donora, Pa. - Preliminary Report. Public Health Bull. No. 306, 1949. pp. 11-54.

117. U. S. Public Health Service. Air pollution research conducted and supported by the Public Health Service, fiscal year 1960. Project No. APM-542.2, 542.3, 542.4 - Air pollution and community health in Nashville - a prototype study. Investigators: Zeidberg, L. D. et al. U. S. Public Health Service, Washington 25, D. C. Aug. 1960.

118. Zeidberg, L. D., Prindle, R. A., and Landau, E. The Nashville air pollution study. I. Sulfur dioxide and bronchial asthma. A preliminary report. Amer. Rev. Respirat. Diseases. 84:489-503. Oct. 1961.

119. Dohan, F. C. and Taylor, E. W. Air pollution and respiratory disease. A preliminary report. Am. J. Med. Sci. 240:337-39. Sept. 1960.

120. Spicer, W. et al. Pulmonary function studies in Baltimore. To be presented at the American Thoracic Society Annual Meeting, Cincinnati, Ohio. May 22, 1961.

121. Ciocco, A. and Thompson, D. J. A follow-up of Donora ten years after: methodology and findings. Am. J. Public Health. 51:155-64. Feb. 1961.

122. Skvortsova, N. N. Pollution of atmospheric air with carbon monoxide in the vicinity of ferro-metallurgical plants. In: U.S.S.R. Literature on Air Pollution and Related Occupational Diseases - Vol. 2. pp. 204-12. (See reference 111).

123. U. S. Public Health Service. Air pollution research conducted and supported by the Public Health Service, fiscal year 1960. Project No. APM-653.1 - Relationship of sudden changes in steel production to changes in mortality. U. S. Public Health Service, Washington 25, D. C. Aug. 1960.

124. Hallgren, W., Karlsson, N., and Wramby, G. Molybdenum poisoning ("molybdenosis") in cattle in Sweden. Nord. Vet. Med. 6:469-80. 1954. (Abstract 155 in reference 115).

125. Murray, M. M. and Wilson, D. C. Fluorine hazards with special reference to some social consequences of industrial processes. Lancet. 251:821-24. 1946. (Abstract 48 in reference 115).

126. American Conference of Governmental Industrial Hygienists. Threshold limit values for 1960. Arch. Environ. Health. 1:140-44. Aug. 1960.

127. Elkins, H. B. Maximum acceptable concentrations, a comparison in Russia and the United States. Arch. Environ. Health. 2:45-49. Jan. 1961.

128. The maximum allowable concentrations of an air pollutant to be used for hygienic evaluation of the air in populated areas. In: U.S.S.R. Literature on Air Pollution and Related Occupational Diseases - Vol. 2. p. 260. (See reference 111).

129. Evans, E. E. An X-ray study of industrial gases on the human lung. Radiology. 34:411-24. 1940. (Abstract 468 in reference 115).

130. Kehoe, R. A. et al. Effects of prolonged exposure to sulfur dioxide. J. Ind. Hyg. 14:159-73. 1932. (Abstract 446 in reference 115).

131. Myers, J. A., ed. Diseases of the Chest Including the Heart. Charles C. Thomas Co., Springfield, Ill., 1959. pp. 520-29.

132. Anderson, W. A. D. Pathology. C. V. Mosby Co., St. Louis, Mo., 1948. pp. 164, 167.

13. Gleason, M. N., Gosselin, R. E., and Hodge, H. C. Clinical Toxicology of Commercial Products. Williams and Wilkins Co., Baltimore, Md., 1957. pp. 160, 169.

134. Patty, F. A. Industrial Hygiene and Toxicology. Vol. 2. Interscience Publishers, Inc., New York, N. Y., 1949. pp. 607-09.

135. Vigliani, E. C. and Zurlo, N. Experiences of the Clinica del Lavoro with some maximum allowable concentrations (MAK) of industrial poisons. Arch. Gewerbepathol. Gewerbehyg. 13:528-34. 1955. (Abstract 594 in reference 115).

136. Vigdorchik, N. A. et al. The symptomatology of chronic poisoning with oxides of nitrogen. J. Ind. Hyg. Toxicol. 19:469-73. Nov. 1937.

137. Grollman, A. Pharmacology and Therapeutics. 4th ed. Lea and Febiger, Philadelphia, Pa., 1960. pp. 709, 978.

138. Novikov, Yu. V. Effect of small benzene concentrations on higher nervous activity of animals in chronic experiments. In: U.S.S.R. Literature on Air Pollution and Related Occupational Diseases. Vol. 2. pp. 185-91. (See reference 111).

139. Beck, H. G. The clinical manifestations of chronic carbon monoxide poisoning. Ann. Clin. Med. 5:1088-96. 1927. (Abstract 431 in reference 115).

140. Goldsmith, J. R. Recurrent carbon monoxide exposure. Presented at Western Industrial Hygiene Conference, San Francisco, Calif. Oct. 7, 1960.

141. U. S. Public Health Service. Air pollution research conducted and supported by the Public Health Service, fiscal year 1960. Project No. APM-433.1 - Epidemiologic studies on the carbon monoxide content of blood from specific population groups. U. S. Public Health Service, Washington 25, D. C. Aug. 1960.

142. Roebber, H. M. In: Fourth Saranac Laboratory Symposium on Silicosis. The Edward C. Trudeau Foundation, Saranac Lake, N. Y., 1939. p. 241.

143. Ivanova, M. G. and Ostrovskaya, I. S. The effect of aluminum dust on the animal organism. In: U.S.S.R. Literature on Air Pollution and Related Occupational Diseases - Vol. 2. pp. 167-74. (See reference 111).

144. King, E. J. et al. The effect of aluminum and of aluminum containing 5 percent of quartz in the lungs of rats. J. Pathol. Bacteriol. (London). 75:429-34. Apr. 1958.

145. Mitchell, J., Manning, G. B., Molyneux, M., and Lane, R. E. Pulmonary fibrosis in workers exposed to finely powdered aluminum. Brit. J. Ind. Med. 18:10-20. Jan. 1960.

146. Schepers, G. W. H. and Delahant, A. B. Prevention of "silica shock" by aluminum. Arch. Environ. Health. 2:9-15. Jan. 1961.

147. Sander, O. A. Foundry workers' pneumoconiosis. Arch. Ind. Hyg. and Occupational Med. 10:512-21. Dec. 1954.

148. Dechoux, J. Pneumoconiosis in iron ore miners in the Lorraine Basin. Nancy, Imprimerie Georges Thomas, 1954. 170 pp. (Abstract 570 in reference 115).

149. Gross, P., Westrick, M. L., and McNerney, J. M. The pulmonary response to blast furnace stack gas. AIHA J. 20:197-204. June 1959.

150. Sadoul, P. et al. Pneumoconioses of iron miners and their functional consequences. Minerva Med. (Turin). 49:4689-93. Dec. 12, 1958.

151. Hueper, W. C. Role of occupational and environmental air pollutants in production of respiratory cancer. Arch. Pathol. 63:427-50. May 1957.

152. Levin, M. L., Kraus, A. S., Goldberg, I. D., and Gerhardt, P. R. Problems in the study of occupations and smoking in relation to lung cancer. Cancer. 8:932-36. Sept.-Oct. 1955.

153. McLaughlin, A. I. G. and Harding, H. E. Pneumoconiosis and other causes of death in iron and steel foundry workers. A. M. A. Arch. Ind. Health. 14:350-78. Sept. 1956.

154. Guthred, K. G. and Flynn, M. J. Some aspects of chronic respiratory diseases in coal miners in New South Wales, Australia. Diseases of the Chest. 37:390-99. Apr. 1960.

155. Belknap, E. L. Saranac Laboratory Symposium, National Tuberculosis Association. The Edward C. Trudeau Foundation, Saranac Lake, N. Y., 1941. p. 123.

156. U. S. Public Health Service. Air pollution research conducted and supported by the Public Health Service, fiscal year 1960. Project No. APM-432.2 - Geographic and temporal variations in lead levels of blood and urine. U. S. Public Health Service, Washington 25, D. C. Aug. 1960.

157. Elstad, D. Manganese-containing dust as a predisposing factor for pneumonia epidemics in an industrial region. Nord. Med. 3:2527-33. 1939. (Abstract 36 in reference 115).

158. McLaughlin, A. I. G. and Harding, H. E. The causes of death in iron and steel workers (non-foundry). Brit. J. Ind. Med. 18:33-40. Jan. 1961.

159. Sepke, G. Silicosis following sublimial exposure to dust. Tuberkulosearzt (Stuttgart). 12:638-42. Oct. 1958.

160. Amdur, M. O. The physiological response of guinea pigs to atmospheric pollutants. Intern. J. Air Pollution. 1:170-83. Jan. 1959.

161. U. S. Public Health Service. Air pollution research conducted and supported by the Public Health Service, fiscal year 1960. Project No. APM-411.1 - Measurement of pulmonary physiological responses to air pollutants. Investigators: Whittenberger, J. L. and Roberts, A. U. S. Public Health Service, Washington 25, D. C. Aug. 1960.

162. Hueper, W. C. et al. Carcinogenic bioassays on air pollutants. Arch. Pathol. 74:89-116. Aug. 1962.

163. Sawicki, E. et al. loc. cit.

164. Barkley, J. F. Fundamentals of smoke abatement. Information Circular 7588, U. S. Bureau Mines, Dec. 1950. 34 pp.

165. McCabe, L. C., Rose, A. H., Hamming, W. J., and Viets, F. H. Dust and fume standards. Ind. Eng. Chem. 41:2388-90. Nov. 1949.

166. U. S. Dept. of Health, Education and Welfare, Public Health Service. Unpublished data. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

167. Robert A. Taft Sanitary Engineering Center. Air pollution measurements of the national air sampling network, 1953-1957. PHS Publ. 637. 1958. 259 pp.

168. Mills, J. L. et al. Emissions of oxides of nitrogen from stationary sources in Los Angeles County. Report No. 3, Oxides of nitrogen emitted by medium and large sources. Los Angeles County Air Pollution Control District, Los Angeles, California, Apr. 1961. 51 pp.

169. Dagan, B. N. The cleaning of open hearth waste gases. Unpublished paper, Kaiser Steel Corporation, Fontana, Calif.

170. Dust removal in oxygen steelmaking. J. Metals. 12:554-57. July 1960.

Table A1. BLAST FURNACE CAPACITY January 1, 1960 (Reference 1)

State	Number of plants	Number of furnaces	Annual capacity (net), tons	Percent of total capacity
Pennsylvania	23	76	26, 381, 750	27. 3
Ohio	22	52	18, 734, 500	19. 4
Indiana	3	23	10, 324, 350	10. 7
Illinois	6	22	7, 955, 200	8. 2
New York	6	17	5, 947, 000	6. 2
Alabama	7	22	5, 817, 440	6. 0
Maryland	1	10	5, 480, 000	5. 7
Michigan	3	9	5, 290, 250	5. 5
West Virginia	2	5	2, 646, 000	2. 7
California	1	4	1, 997, 800	2. 1
Utah	2	5	1, 804, 200	1. 9
Kentucky	1	3	1, 058, 000	1. 1
Texas	2	2	925, 000	1. 0
Colorado	1	4	922, 400	1. 0
Minnesota	2	3	696, 000	0. 7
Tennessee	2	3	217, 740	0. 2
Massachusetts	1	1	195, 000	0. 2
Virginia	1	2	128, 000	0. 1
Total	86	263	96, 520, 630[a]	100. 0

[a] Includes 877, 500 tons ferroalloys capacity.

Table A2. ANNUAL COKE CAPACITY OF THE IRON AND STEEL INDUSTRY January 1, 1960 (Reference 1)

State	Number of plants	Number of ovens	Annual capacity (net), tons	Percent of total capacity
Pennsylvania	16[a]	5,365[a]	20,672,100[a]	28.5
Ohio	12	2,201	11,348,500	15.7
Indiana	3	1,963	9,819,000	13.6
Alabama	5	1,225	6,149,900	8.5
Maryland	1	758	4,174,000	5.8
West Virginia	3	668	3,856,000	5.3
New York	2	710	3,629,000	5.0
Michigan	2	514	3,460,000	4.8
Illinois	5	476	2,638,000	3.7
California	1	315	1,502,000	2.1
Utah	2	308	1,434,600	2.0
Colorado	1	237	985,500	1.4
Minnesota	2	176	893,600	1.2
Texas	2	140	832,000	1.2
Massachusetts	1	108	664,000	0.9
Tennessee	1	44	251,500	0.3
Total	59[a]	15,208[a]	72,309,700[a]	100.0

[a] Includes four coke plants with 1,392 beehive ovens and a capacity of 877,100 net tons per year.

Table A3. ANNUAL OPEN HEARTH CAPACITY January 1, 1960 (Reference 1)

State	Number of plants	Number or furnaces	Annual Capacity (net), tons	Percent of total capacity
Pennsylvania	30	283	34, 944, 350	27. 6
Ohio	17	169	22, 688, 280	17. 9
Indiana	4	120	18, 339, 000	14. 4
Illinois	6	62	9, 842, 000	7. 8
Maryland	1	35	7, 864, 000	6. 2
New York	3	47	7, 195, 000	5. 7
Michigan	2	27	5, 420, 000	4. 3
Alabama	3	31	4, 786, 000	3. 8
West Virginia	1	14	3, 300, 000	2. 6
California	6	30	2, 727, 500	2. 2
Utah	1	10	2, 300, 000	1. 8
Texas	2	13	1, 825, 000	1. 4
Colorado	1	17	1, 800, 000	1. 4
Kentucky	2	15	1, 363, 000	1. 1
Minnesota	1	9	973, 000	0. 8
Delaware	1	7	506, 500	0. 4
Missouri	1	4	420, 000	0. 3
New Jersey	1	9	235, 000	0. 2
Rhode Island	1	4	93, 000	0. 1
Total	84	906	126, 621, 630	100. 0

Table A4. ELECTRIC FURNACE CAPACITY January 1, 1960 (Reference 1)

State	Number of plants	Number of furnaces	Annual capacity (net), tons	Percent of total capacity
Ohio	8	36	3,078,600	21.4
Pennsylvania	31	105	2,888,780	20.1
Illinois	8	28	2,400,400	16.6
Michigan	4	20	1,178,600	8.1
Texas	5	12	699,080	4.8
Alabama	4	8	670,020	4.6
California	3	8	628,000	4.4
Kentucky	2	5	466,190	3.2
Missouri	1	2	420,000	2.9
Washington	3	6	401,000	2.8
Georgia	1	2	325,000	2.3
New York	6	28	225,010	1.6
Maryland	2	11	180,960	1.3
Oregon	1	3	150,000	1.0
Oklahoma	1	1	140,000	1.0
West Virginia	1	1	117,000	0.8
Indiana	2	7	101,500	0.7
Connecticut	1	2	84,000	0.6
Arizona	1	2	60,000	0.4
Florida	1	1	51,000	0.4
Mississippi	1	1	45,000	0.3
Virginia	2	4	40,000	0.3
Tennessee	1	2	38,000	0.3
New Jersey	1	6	7,800	0.1
Total	91	301	14,395,940	100.0

Table A5. BESSEMER FURNACE CAPACITY January 1, 1960 (Reference 1)

State	Number of plants	Number of furnaces	Annual capacity (net), tons	Percent of total capacity
Ohio	4	9	2, 552, 000	75. 1
Pennsylvania	2	6	408, 000	12. 0
Maryland	1	3	336, 000	9. 9
Illinois	1	3	100, 000	3. 0
Alabama	1	3	a	
Indiana	1	3	a	
Michigan	1	2	a	
West Virginia	1	3	a	
Total	14	31	3, 396, 000	100. 0

[a] Bessemer converters used in melting charge for open hearth furnaces.

Table A6. BASIC OXYGEN STEEL PRODUCTION CAPACITY January 1, 1960 (Reference 1)

State	Number of plants	Number of furnaces	Annual capacity (net), tons	Percent of total capacity
California	1	3	1, 440, 000	34. 6
Michigan	1	5	1, 385, 400	33. 4
Pennsylvania	1	2	880, 000	21. 1
Illinois	1	2	452, 000	10. 9
Total	4	12	4, 157, 400	100. 0

Table A7. SLOT-TYPE COKE OVENS IN EXISTENCE, CONSTRUCTED, AND ABANDONED IN THE UNITED STATES, 1900-1960 (Reference 22)

Year	In Existence end of year			Number of ovens constructed	Number of ovens abandoned
	Number of plants	Number of ovens	Annual capacity (net), tons		
1900	-	475	-	60	-
1910	-	2,610	-	49	-
1920	-	8,265	-	934	376
1930	-	9,342	-	265	164
1940	-	9,188	-	-	245
1942	-	9,722	-	361	-
1944	-	11,236	-	503	114
1946	-	11,289	-	157	218
1948	-	12,156	-	583	168
1950	-	12,020	-	485	586
1952	-	12,827	-	907	441
1954	58	13,298	67,909,300	633	631
1956	57	13,499	68,955,500	361	360
1958	55	13,824	71,467,100	808	461
1959	55[a]	13,816[a]	71,432,600	-	-

[a] From reference 16.

Table A8. AGE OF SLOT-TYPE COKE OVENS IN THE UNITED STATES December 31, 1958 (Reference 22)

Age, yr	Number of ovens	Percent of total	Annual capacity (net), tons	Percent of total
Under 5	2,341	17.0	12,453,300	17.4
From 5 to 10	3,598	26.1	19,650,000	27.5
From 10 to 15	1,805	13.0	9,838,500	13.7
From 15 to 20	2,242	16.2	12,021,100	16.8
From 20 to 25	1,053	7.6	5,973,900	8.4
From 25 to 30	132	1.0	750,600	1.1
From 30 to 35	323	2.3	1,590,200	2.2
From 35 to 40	719	5.2	3,008,800	4.2
40 and over	1,611	11.6	6,180,700	8.6
Total	13,824	100.0	71,467,100	100.0

Table A9. PIG IRON AND FERROALLOYS - CAPACITY AND PRODUCTION 1920 to 1957 (Reference 26)

Years	Number of furnaces	Capacity (Jan. 1) 1,000's of short tons	Production, 1,000's of short tons			Production, percent of capacity
			Total	Pig iron	Ferroalloy	
1920	453	56,249	41,179	40,593	586	73.2
1930	316	57,855	35,338	34,743	594	61.1
1940	232	55,724	46,979	46,072	907	84.3
1950	248	71,560[a]	65,440	64,587	853	91.4
1954	260	82,001	58,687	57,966	721	71.6
1955	261	83,971	77,790	76,857	932	92.6
1956	261	85,485	75,960	75,068	891	88.9
1957	262	86,818	79,339	78,375	964	91.4
1958	265[b]	91,000	-	-	-	-
1960	263[c]	96,521	-	-	-	-

[a] Average annual capacity as of January 1 and July 1.

[b] From 27th edition of Reference 16.

[c] From Reference 16.

Table A10. STEEL CAPACITY AND PRODUCTION OF INGOTS AND STEEL FOR CASTINGS, BY TYPE OF FURNACE, 1920 - 1957 (Reference 26)

Year	Capacity (Jan. 1) 1,000's of short tons	Production, 1,000's of short tons							Production, percent of capacity
		Total	Open Hearth			Bessemer	Electric	Cru-cible	
			Total	Basic	Acid				
1920	60, 220	46, 183	35, 846	--	--	9, 841	417	79	76. 7
1925	65, 962	49, 705	41, 804	--	--	7, 474	406	20	75. 4
1930	71, 042	44, 591	38, 587	--	--	5, 623	379	2	62. 8
1935	78, 452	38, 184	34, 401	34, 005	397	3, 175	606	1	48. 7
1940	81, 619	66, 983	61, 573	60, 883	690	3, 709	1, 700	1	82. 1
1945	95, 505	79, 702	71, 940	71, 070	870	4, 305	3, 457	a	83. 5
1946	91, 891	66, 603	60, 712	60, 112	600	3, 328	2, 563	b	72. 5
1947	91, 241	84, 894	76, 874	76, 209	665	4, 233	3, 788	b	93. 0
1948	94, 233	88, 640	79, 340	78, 715	625	4, 243	5, 057	b	94. 1
1949	96, 121	77, 978	70, 249	69, 742	507	3, 947	3, 783	b	81. 1
1950	99, 983[c]	96, 836	86, 263	85, 662	601	4, 535	6, 039	b	96. 9
1951	104, 230	105, 200	93, 167	92, 387	779	4, 891	7, 142	b	100. 9
1952	108, 588	93, 168	82, 846	82, 143	703	3, 524	6, 798	b	85. 8
1953	117, 547	111, 610	100, 474	99, 828	646	3, 856	7, 280	b	94. 9
1954	124, 330	88, 312	80, 327	79, 923	405	2, 548	5, 436	b	71. 0
1955	125, 828	117, 036	105, 359	104, 805	555	3, 320	8, 357[d]	b	93. 0
1956	128, 363	115, 216	102, 841	102, 168	673	3, 228	9, 148[d]	b	89. 8
1957	133, 459	112, 715	101, 658	101, 028	630	2, 475	8, 582[d]	b	84. 5
1958	140, 743	--	--	--	--	--	--	--	--
1960	148, 571[e]	--	--	--	--	--	--	--	--

[a] Less than 500 short tons.

[b] Include with electric.

[c] Average of January 1 and July 1.

[d] Includes steel made by the basic oxygen process.

[e] From reference 16.

Table A11. SIZE AND LOCATION OF BASIC OXYGEN FURNACES IN NORTH AMERICA (Reference 15)

Company and plant location	Startup date	Number of furnaces	Rated capacity (net), tons	Actual production, tons/heat	Oxygen blown, cfm
Dominion Foundry & Steel Hamilton, Ontario	Oct. 1954	2	30	50	3,000
	Dec. 1956	1	60	-	-
McLouth Trenton, Mich.	Dec. 1954	3	35	50	3,500
	Apr. 1958	2	80	-	-
	Mar. 1960	1	110	-	-
Jones & Laughlin Aliquippa, Pa.	Nov. 1957	2	65	81 to 108	6,000 to 8,000
Algoma Sault Ste-Marie, Ontario	Nov. 1958	2	65	100	8,000
Kaiser Fontana, Cal.	Dec. 1958	3	65	120	-
Acme Chicago, Ill.	Jan. 1959	2	55	-	3,000 to 4,000
Colorado Fuel & Iron Pueblo, Colo.	1st qtr. 1961	2	100	-	-
Jones & Laughlin Cleveland, Ohio	2nd qtr. 1961	2	200	-	12,000 to 20,000

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